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Edited by
ALAN WOOD

(Authors alone are responsible for the opinions and facts stated in their respective papers, and for the accuracy of their references)

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PROCEEDINGS
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STREAM PROFILES IN THE VALE OF EDALE, DERBYSHIRE.

By W. V. LEWIS, M.A.

A FIELD MEETING of students from the Cambridge School of Geography in June, 1941, provided an opportunity to survey several short but deep-cut ravines near Edale, Derbyshire. A series of laboratory experiments with stream profiles (Lewis, 1944) had just been completed, and these small ravines showed promise of yielding data at scales between those of the laboratory experiments and of normal river valleys.

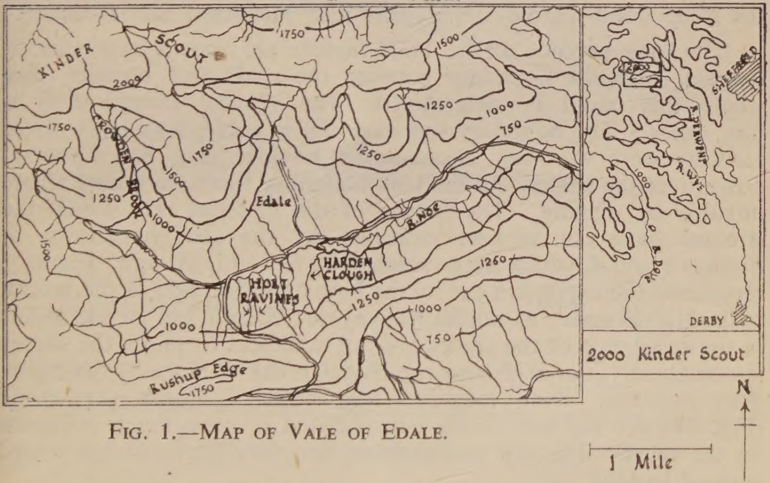

FIG. 1.—MAP OF VALE OF EDALE.

The Edale streams had, in post-glacial times, incised their courses in non-resistant and relatively homogeneous drift and shales. Active erosion still continues, and only a few days before our visit numerous large scars had been cut by floods of quite exceptional severity. Thus we were fortunate in being able to examine unusually large and fresh exposures of boulder clay and shales. Digging indicated that this boulder clay—in places fully 30 feet thick—rested on the Edale Shales. This thickness surprised us in view of Edwards's assertion (p. 182) that no unmistakeable boulder clay, nor the usual marks of glaciation, occur in the area.

The Edale Shales (Jackson, p. 18) consist of black argillaceous and carbonaceous shales with bands of hard, rounded nodules of earthy limestone at certain levels. In the lower part of the series, beds of thin, black, earthy limestones are interbedded with argillaceous shales and hard mudstones.

A thin layer of boulder clay covers much of the lower slopes of the wide U-shaped valley of the Noe at the foot of Kinder Scout (The Peak). The main stream has cut through into the underlying soft Edale Shales, and has incised its channel in places to 50 feet below the general level of the valley floor. Owing to this "rejuvenation" the small tributaries have, in their lower courses, cut down into the boulder clay and frequently into the shales below, forming ravines which deepen towards the main stream. The Holt ravines comprise two tributaries which unite near the River Noe (Fig. 1) after following parallel, then slightly converging courses. The slopes of the valley adjacent to the ravines, the stream channels, and numerous cross sections were accurately levelled. Several of the newly revealed exposures of the boulder clay and shales on the steep flood-scarred slopes were also measured and sketched.

The long profiles of the Holt ravines are shown in Figure 2, together with the boundary between the shale and boulder clay where this could be determined. The vertical exaggeration is four times. The boundary was in doubt in some cases even where sections were exposed, because the boulder clay had slumped down over the shales, but the true boundary was ascertained where possible by digging. The nature of the material into which the streams have cut is best indicated by the sections shown in Figures 3 and 4, which were sketched by Miss M. Waugh. Figure 3 represents the exposures cut by the Noe on either side of the mouth of the Holt ravine. Minor faults (a a) are frequent, but the variations in the resistance of the shales are not sufficient to affect the slopes systematically, nor is there a significant break of slope at the shale-drift junction. Even localised thin beds of coarse sand-stone (Fig. 4B) are not sufficiently consolidated to have much influence on the relief. The dip was variable, but very gentle except where warped locally.

The levelling staves were held on the bed of the streams when the profiles (Fig. 2) were being measured. A remarkable feature was the little hang of 2½ to 3 feet at the junction with the Noe. The floor of the ravine hung fully 4 feet above the normal water surface of the Noe, but the stream had cut down into this floor slightly, lessening the fall at the actual junction. A small terrace of angular stones flanked the little stream for a dozen or so yards before it entered the Noe. These and other signs of deposition in the mouth of the ravine by the recent flood, indicated that the ravine is graded to the flood level of the Noe. The small trench, nearly two feet deep at its mouth, but cut back only a few yards into the overhang illustrated the impotence of the little stream during normal weather conditions : this in spite of the fact that flood conditions must prevail for only a few days each year. It would seem, therefore, that the ravine is cut almost entirely during the short bursts of violent flood activity, eloquent testimony to the effect of increase of discharge on the power of a stream.

The gradient from the junction of the two little streams to the ravine mouth is very similar to that of the main valley floor above, but the gradients of both tributaries increase upstream at a greater rate than that of the valley floor. The left tributary carried

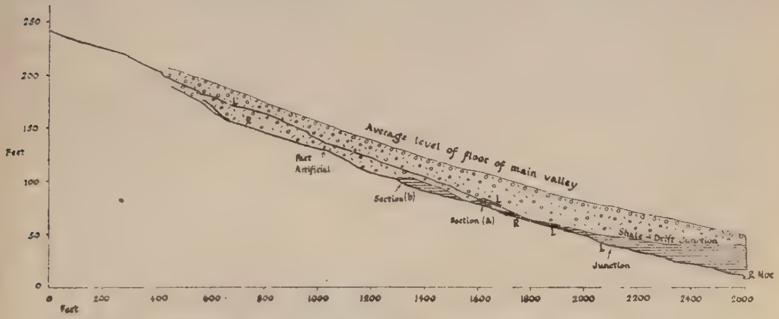

FIG. 2.—LONG PROFILES OF HOLT RAVINES.

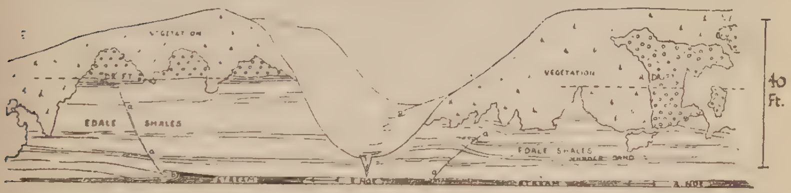

FIG. 3.—SECTION ACROSS MOUTH OF HOLT RAVINE.

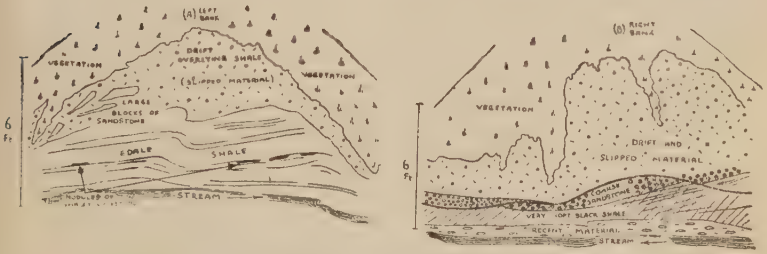

FIG. 4.—EXPOSURES IN SIDES OF HOLT RAVINE.

0.11 cu. ft./sec. when measured, compared with only 0.04 in the right one, which had nevertheless cut its profile much lower. This latter profile had two distinct breaks of slope, one at 1,300 feet, and the other at 1,050 feet (point 1050) from the beginning of the section. The latter break was in part artificial where a path crossed the stream. The uppermost break of slope or nick point seemed to have retreated to about point 600, where the stream further subdivided before ending just below the tongue of a great mass of landslipped material. It is possible that the landslip has affected the volume of water reaching this tributary. It seems more likely, however, that the building of the road has led off some water from the right to the left tributary, for the road over Rushup Edge (Fig. 1) crosses the head-waters of both streams, but slopes steeply from the right to the left tributary.

The left tributary had three distinct nick points at points 975, 570 and 450. A further slight one at point 300 brought the stream right up on to the surface of the main valley, and so represented the upstream limit of the ravine. It was not easy to relate these or any of the other lesser breaks of slope to hard bands in the Edale Shales, nor in the boulder clay, though the possible influence of large boulders must not be overlooked. The nick points seemed to form a natural, and perhaps essential, part of the active down cutting processes of the little streams on these steep and easily eroded slopes.

The gradient of the right tributary flattens markedly at the first junction (point 680) from 1 : 6 to 1 : 11, and again from 1 : 13 to 1 : 17 at the junction with the left tributary (point 2100). This seems to illustrate the ability of a combined stream to erode more effectively than its tributaries if conditions, other than discharge, remain approximately similar. It would appear that the increase of volume at the junction increases the power of the stream to erode and so enables it to lower its course rapidly at that point. This, however, would increase the load, and so downstream the surplus energy would gradually be absorbed in carrying this extra material, and therefore at first erosion might tend to be localised at the junction. Increased down-cutting immediately below the junction, not accompanied by equal erosion further downstream, would inevitably reduce the gradient of the combined stream. Thus a stage might be expected at which the increased erosive power of the main ravine stream, compared with the tributaries, would be counter-balanced by a reduction of gradient, and so a condition of approximate equilibrium be attained. In this matter of stream gradients it is interesting to note that O. T. Jones (p. 589) disagreed with Penck's assertion that the long profile of tributary streams grade imperceptibly into that of the main stream, and considered a break of slope at the junction more likely. The Edale streams seem a very apt illustration of Jones's thesis, for in each case the combined streams show a gentler gradient than either tributary. They probably exhibit this characteristic well because time has not sufficed for the steep slope above the junction to have receded far upstream and so conceal the fact that it originated at the junction. Perhaps this process can be seen at work with the left tributary, which for a hundred yards above the junction follows a gradient of 1 : 13 ; then at point 1800 it increases abruptly to 1 : 9. At point 1500, however, it flattens again to 1 : 11. The two minor tributaries at point 600 seem barely to have begun this process of cutting back.

A second ravine, Harden Clough, in a similar position less than a mile downstream, was surveyed by clinometer and tape. This ravine is incised deeply where the floor of the Noe Valley, into which it is cut, slopes steeply, but the incision is slight where the slope is gentle. There is far greater variation of slope down the side of the Noe Valley here than at the Holt ravines, and so the powerful influence of gradient on the effectiveness of stream erosion is better illustrated at Harden Clough than at Holt. The importance of slope is also illustrated at many points by the variation in the depth of the trench cut by the Noe itself.

A small dam had been built across Harden Clough to provide a head of water for a domestic electric plant. The rapid accumulation of silt in the reservoir necessitated the latter being cleared out periodically, and this had been last done four years before our visit. The volume of the accumulated silt was measured by probing along closely-spaced parallel section lines ; heights were fixed by levelling. The volume of silt behind the dam was assumed to have accumulated since the last removal of the silt four years previously. At this rate of removal the whole ravine could have been sculptured in 5,000 years. The true valley section is that of a V-in-V, the lower V forming the ravine, and the upper one having very gentle slopes. If this latter were included in the true volume of excavated material, the time for sculpturing is raised to 9,000 years. This allowance is probably too large as the outer gently-sloping valley must have been at least in part inherited by the stream. A similar gently-sloping upper valley occurs at the Holt ravines, the volumes of which, as at Harden Clough, are rather less than those of the ravines proper.

If the little streams commenced their task as soon as the ice left the valley, the period 9,000 years seems too low, but it is of the right order. Many factors could affect this rather rough calculation. The main disturbing factor would seem to be the gradual increase in the gradient of Harden Clough as the Noe cut down into the valley floor. This would lead to the present rate of erosion of Harden Clough being faster than the average, allowance for which would raise the figure above 9,000 years. On the other hand some material is carried over the dam in suspension during times of flood. Also one would have expected a period of very rapid erosion to have immediately succeeded the disappearance of the ice, as occurs in Iceland at present, where much loose surface material is not covered by a protecting mat of vegetation (Lewis, 1939, p. 153).

In view of the lack of relationship between the discharge, as measured in June, 1941, of the two Holt streams and the volume of their ravines, the close accordance between the Holt and Harden Clough ravines should be noted. The average gradient and bed material is similar in both areas. The following table summarises the results :

Name.	Volume of ravine. (cu. ft.).	Discharge of stream. (cu. ft./sec.).	Watershed area (sq. miles.).
Holt ravine (right)	1,740,000	0.04	
Holt ravine (left)	964,700	0.11	
Holt ravines (left, right and main)	3,978,000	0.15	0.179
Harden Clough	3,954,000	0.17	0.170

In conclusion, the above examples of stream erosion seem to lend support to two fundamental propositions of Gilbert (p. 109) :

(i) An increase of gradient results in a great increase in the capacity of a stream to transport and erode.

(ii) An increase of discharge results in a great increase in the capacity of a stream to transport and erode.

A corollary to (ii), highly significant in the study of the curve of water erosion, is that as a stream increases in volume it can carry its load down a gentler slope even though the load increases proportionally with volume.

A third point of interest is the frequency of nick points. Some are related to junctions, others might be due to variations in the resistance of the deposits to stream erosion, variations which are not sufficient to influence the slopes of the ravine sides. It seems that nick points might be a quite normal feature in a stream course that is suffering erosion, due to almost imperceptible variations in the resistance of the deposits, and to the tendency of nick points to be self-propagating when once formed. My attention has been called to a further factor that might be responsible for some of these nick points. The landslides illustrate the present instability of the slopes of the Noe Valley. The countless minor contortions and faults in the Edale Shales further suggest that this formation might have been squeezed out into the valley floor, by the pressure of the overlying strata forming the steep valley sides. Such movements have been demonstrated in the Northampton Ironstone Field

(Hollingworth, Taylor and Kellaway, p. 4), where the relief is far less than in the Vale of Edale. Any such movements have not, however, been sufficient to affect the lower slopes of the Noe Valley on either side of the ravines. For their smooth mature slopes contrast strongly with the hummocky disturbed ground affected by the landslips on the steep upper slopes of the valley.

I wish to express my thanks to Professor Debenham, who organised the field meeting and first conceived the plan to survey the ravines ; to Mr. E. E. Benest, who had charge of the levelling ; to the students who carried it out ; to Mr. D. F. Munsey for helpful criticisms, and to Mrs. R. W. Wood for drawing the diagrams.

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THE VALLEY SYSTEM OF LYME REGIS

By MURIEL A. ARBER, M.A., F.G.S., F.R.G.S.

I. INTRODUCTION.

"LIME is a praty market toun set in the rootes of an high rokky hille down to the hard shore. . . . Ther cummith a shalow brooke from the hilles about a 3. miles of by north, and cummith fleting on great stone thorough a stone bridge in the botom. The tounes men communely caul this water the Buddel."

The river thus described by Leland (1535-1543) is formed of the united waters of five streams rising in Devon and crossing the county boundary into Dorset at Uplyme, to flow as the Lym down to the sea, where Lyme Regis stands on its little estuary known as the Buddle. The country behind Lyme, carved by the five valleys of Harcombe, Rocombe, Yawl, Holcombe and Cannington, constitutes a completely self-contained drainage area, its circumscribing watershed being an unbreached ridge almost entirely above 500 feet O.D. (Fig. 5). Stratigraphically, the district has much in common with the valley of the Axe on the west and with the Vale of Marshwood on the east, but the fact that the relatively small area of the Lym is drained by several sub-equal streams dissecting a plateau, has led to the development of deep narrow valleys unlike those of the neighbouring country.

Where the valleys converge at Uplyme, they form a wide hollow, looking on a misty evening like a great cup in the hills. The lower slopes, cut in Lias clays, show the rich green of well-watered pasture-land, with deep banks and hedgerows interspersed with mixed woodland, rustling with small animals and scented with abundant plant life. Above are the precipitous wooded scarps and level hill-tops of the less fertile Upper Greensand, reddish-brown in spring with dead leaves and bracken. At the valley junctions, the summit-plateau drops into smoothly curved hill-spurs, flanked by steep scarps. At the foot of the scarps is a well-marked terrace which is a stratigraphical feature or rock-bench, while the clay bottoms of the valleys weather into gentle knolly contours, emphasised by the shadows in the evening.

II. GEOLOGY OF THE DISTRICT.

The lower rocks in the district are Lias and Rhaetic clays, shales, marls and limestones, dipping in general east-south-east. These are truncated above by a plane of unconformity dipping somewhat east of south and transgressed by nearly horizontal Gault (loams and clays) and Upper Greensand (Foxmould sands and Chert Beds), with an outcrop of Chalk in the west of the area. The hill-tops form a plateau sloping to the south-east, and covered by

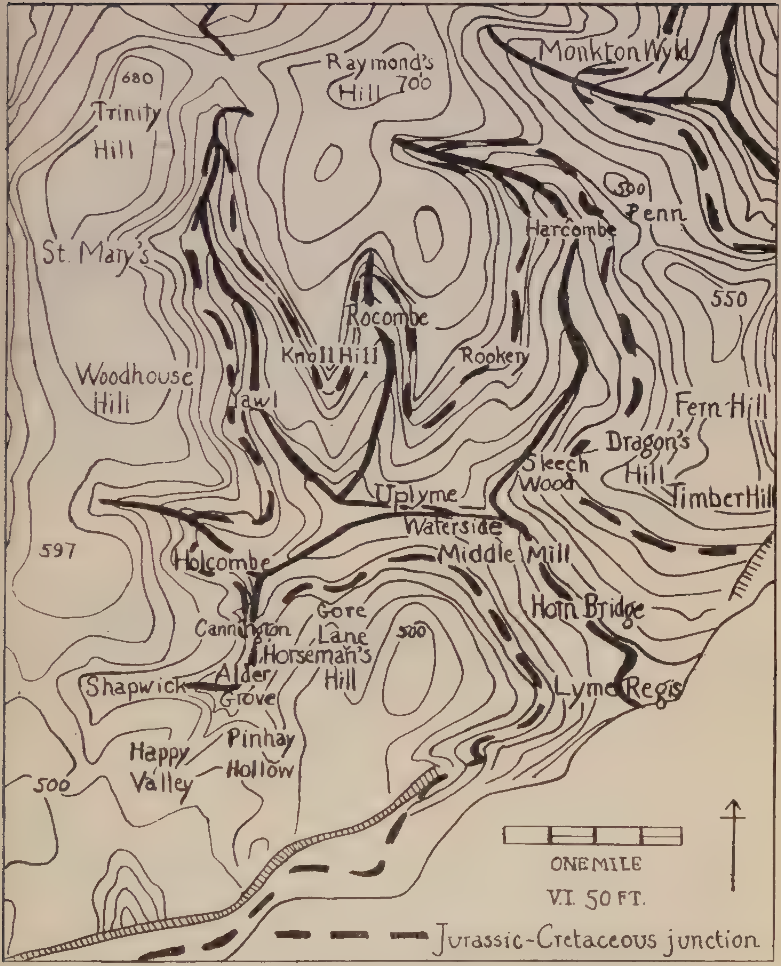


FIG. 5.—SKETCH-MAP OF VALLEY SYSTEM OF LYME REGIS.

Clay-with-Flints, a residual drift deposit. There are few inland exposures, and the details of the beds are inferred mainly from the cliff-section (Lang, 1914).

The Tertiary history of the area appears to have been one of gradual elevation. The hill-top plateau represents a plane of post-Cretaceous denudation, probably marine. Green (1941) has mapped a shore-line of Diestian (older Pliocene) times at 690 feet on the flanks of Trinity Hill, indicating that the north-western summits of the area had probably been raised above sea-level during the preceding Miocene period. Platforms apparently representing shore-lines at 595 feet and 530 feet, which may have belonged respectively to the Casterlian-Scaldisian and later Pliocene times, occur in the west near Pinhay and Shapwick, and indicate by their direction that at this period the Lyme area had already become dry land though still low-lying. The final elevation of the hills through 500 feet to their present height must have continued during the succeeding Pleistocene.

The drainage of the Lym would therefore have been initiated when the area was first raised above sea-level during the early Pliocene. Presumably the original stream joined the Char (Lang, 1926), and thence fed a river flowing down the Channel, since the land-surface is tilted as part of the larger peneplain dipping south from the main Dorset-Somerset watershed (Jukes-Brown, 1898). As in the case of the River Char (Lang, 1926), the evidence of the Lyme valleys also suggests that, apart from minor adjustments, the streams are flowing in their original direction, and were not merely deflected into their present courses by the Miocene uplift, as postulated by Clayden (1906).

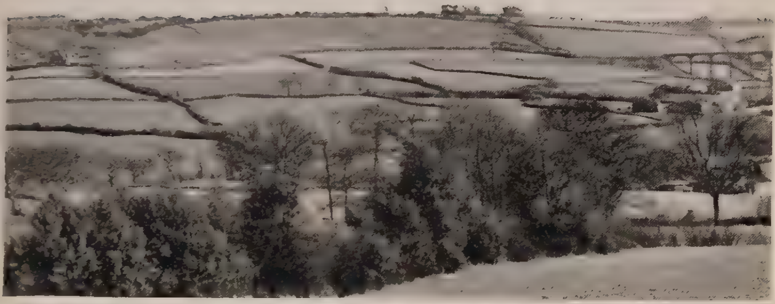
III. STREAM SYSTEM.

The streams all rise as springs in the Upper Greensand (Fig. 5), the water-table being in some cases immediately and in others at some considerable distance above the junction with the underlying clays. The most striking peculiarities of the system are that the Cannington stream turns inland with an elbow-bend at Alder Grove ; and that the confluent Cannington, Holcombe, Yawl and Rocombe streams turn abruptly to the east at Uplyme, form a small flood-plain, and then cut across the apparent grain of the country through a gorge at Waterside. It is recorded (Roberts, 1823, 1834), that in summer the River Lym may sink underground below Sleech Wood and rise again above Middle Mill, but no explanation of this seems to be forthcoming.

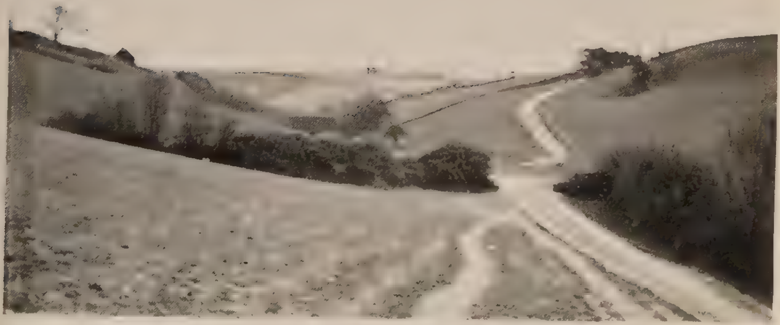
The average gradients of the Harcombe and Yawl streams are almost identical, while the shorter valleys of Rocombe and Holcombe are steeper. Since the water-bearing horizon is lowered in the south by the dip, the gradient of the Cannington stream is little more than half that of Harcombe.

IV. RELATION OF STREAMS TO STRATA.

As the Yawl and Harcombe streams are in the main consequent upon the general dip of the plateau surface, they were presumably the first water-courses to develop. When the whole area was gradually elevated until much of the present sea-floor was also land, the river probably extended further towards the south, until



A.—HORSEMAN'S HILL AND CANNINGTON VALLEY FROM NORTH-WEST.



[Photos : M. A. Arber.

B.—SHAPWICK VALLEY FROM WEST.

[To face p. 10.

its mouth, like that of the other West Dorset streams, was worn back by the severity of the sea's attack on the westward-facing coast [Arber, 1940 (A)]. As the valleys were deepened, the down-cutting gradually exposed the Lias and Rhaetic on which the streams were then superimposed, the deepening being perhaps further emphasised during the wet post-Glacial period (Clayden, 1906).

As the valleys carved through the Upper Greensand, the various water-bearing levels in the sands would be sectioned, forming springs. When the underlying clays then came to be exposed, the sands would be worn back as an escarpment, thus leaving the terrace, roughly at the horizon of the unconformity, which is such a marked feature of the valley scenery (Pl. IA and Pl. 2B). The knolly contours of the clays below might be shown by detailed mapping to depend on stratigraphical features of the Lias and Rhaetic, the softening and rounding being due to slipping of the clays and sands.

The seaward dip of the Cretaceous beds and of the plane of unconformity means that the water-bearing horizons are some 200 feet lower in the south at Shapwick than in the north at Yawl or Harcombe. Since the Cannington stream flows inland against the dip it must be regarded as an obsequent tributary to the Yawl stream ; it would not have been able to develop until the Yawl stream had already cut a valley at Uplyme down to the level of the water-table. Thus, whereas the upper courses of the Harcombe and Yawl streams probably preceded the lower courses in development as the land rose, it seems that the Cannington valley would have developed from Uplyme gradually backwards to its present head. It is possible that the water which now feeds the Cannington stream originally flowed directly out of the cliff-face, as does the water which emerges from the cliffs above the Gault and Lias clays and which is responsible for the landslips along the coast (Arber, 1941). There is an early report (Young, 1840) that charcoal, thrown into a well near Axminster some five or six miles inland, was carried underground to the sea.

The line of the Cannington stream is continued headwards in the dry "Happy"[1] valley, but the stream now rises to the north in the Shapwick valley, making a right-angle turn at Alder Grove (Fig. 5). Possibly as the land-surface was worn down by the development of the Cannington stream, the wide gentle slopes of the Happy valley and of the dry upper course of its Shapwick tributary were eroded in Chalk by surface-water draining towards Cannington. When once the water-bearing horizons below had been sectioned at Shapwick, the water seems to have drained away through the newly-formed line of springs, and so left the Happy and upper Shapwick valleys dry.

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[1] I am indebted to Miss Gulielma Lister for telling me of this name, which is at least 75 years old ; its source is apparently unknown.

Apart from minor tributaries, the Holcombe joins the Cannington stream, and the Rocombe joins the Yawl. Both Holcombe and Rocombe are shorter and steeper than the main valleys, and, having eroded less, they exhibit less benching. The confluent streams may have turned to the east through the Waterside gorge on account of a tendency to follow the strike of the Rhaetic, as the streams of the Vale of Marshwood tend to follow the strike of the Lower Lias (Lang, 1926). Above Waterside gorge, a small flood-plain has been formed, perhaps owing to the check in the current, and another alluvial flat stretches from Sleech Wood to Horn Bridge.

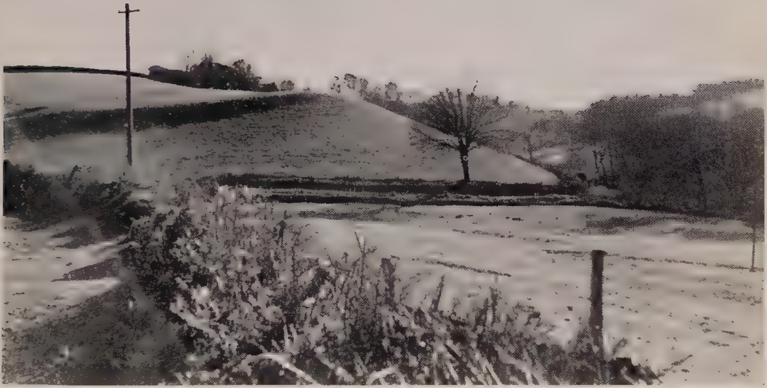
The presence of Chalk in the Happy and Shapwick valleys accounts for the wide smooth curves of their upper hill-sides (Pl. 1B), while the fact that the lower slopes are cut in Upper Greensand has resulted in the comparatively steep V-shape of the valley-bottoms. There is a marked contrast between the even contours of the homogeneous Chalk and sands above and the irregular outlines of the Lower Lias below. In particular, the sloping sandy interfluve spurs are noticeable for their perfectly smooth curves (Pl. 2A), where the drift-covered peneplain surface has been worn down and the capping of Clay-with-Flints removed. The most prominent of these spurs is Knoll Hill (Fig. 5 and Pl. 2B).

V. COMPARISON OF CLIFF AND VALLEY PROFILES.

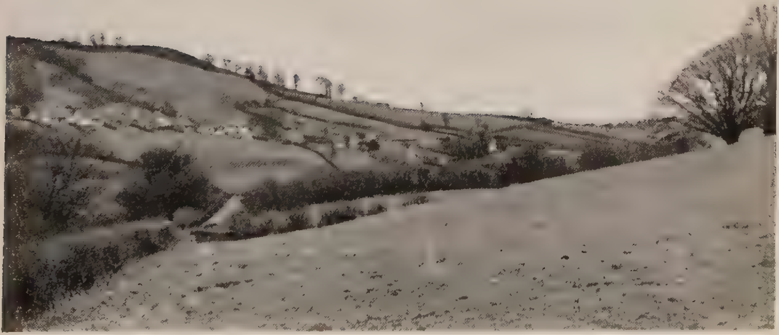
The cross-sections of the Lyme valleys may now be compared with the profiles of the neighbouring cliffs, in which the terracing has already been studied in relation to the horizons at which water is thrown out (Arber, 1941). The principal water-bearing levels in the cliffs are the upper surface of the Lower Lias and certain horizons in the Gault and Foxmould above. The streams of Harcombe, Rocombe and Yawl each rise in the lowest of the Cretaceous beds just above the unconformity, while those of Holcombe and Cannington have their origin in a higher level of the Upper Greensand.

In the valleys, the terrace above the unconformity is thus a precisely similar feature to the terrace which occurs on Black Ven and Stonebarrow, the irregular slope of its overgrown surface in the valleys being due to the accumulation of fallen sands and loams which are heaped up visibly in the corresponding undercliffs.

De la Beche (1839) drew attention to the fact that the washing out of the hillside sands caused landslips in the valleys as on the coast. The precipitous slopes left by the sliding of an entire hillside have been explained as " slip-scarps " in the Charmouth area (Lang and Thomas, 1936) at Coney Castle and elsewhere. This " slip-scarp " hypothesis would provide an explanation of the



A.—INTERFLUVE SPUR AT ALDER GROVE.



[*Photos : M. A. Arber.*

B.—KNOLL HILL AND YAWL VALLEY FROM WOODHOUSE HILL.

[*To face p.* 12.

sheer slopes in the Lyme valleys at Dragon's Hill, the Rookery, Knoll Hill, Woodhouse Hill, Horseman's Hill (Pl. 1A), and Gore Lane. Perhaps on account of the fact that the hill-slopes are now more gentle than the cliffs and are bound by vegetation, large-scale slips have not apparently occurred inland in recent, or even historic, times, although they continue actively in the cliffs to the present day.

At Alder Grove (Pl. 2A) and elsewhere, the ground above the Lias clays is swampy and corresponds to the boggy tracts in the undercliffs. How far the small-scale valley-contours of the Lower Lias can be correlated with the irregularities of the cliffs remains to be discovered.

The remarkable degree of similarity between the profiles of the cliffs and those of the inland hillsides is due to the fact that the erosion of the West Dorset cliffs is at present mainly sub-aerial. The cliff-faces are being worn back by the action of spring-water emerging above the various impervious horizons, and thus producing a stepped profile, the upper terraces of which have gradually receded as much as 300 yards from high water mark [Arber, 1941, (Pl. 20A)]. The material which is thus washed down tends to accumulate in great banks at the foot of the cliff, which is further protected from direct wave-action by a shingle beach. The coast scenery thus produced is in striking contrast to that of a drowned area of hard rocks, such as West Cornwall, where the attack of the sea is cutting the cliffs into a very different form from the slopes seen in the valleys.

VI. SUMMARY AND ACKNOWLEDGMENTS.

The country behind Lyme Regis forms a plateau which is deeply dissected by the five valleys of Harcombe, Rocombe, Yawl, Holcombe and Cannington. Their streams rise in the Upper Greensand and are superimposed on Lias and Rhaetic in the lower parts of their valleys, which unite at Uplyme to form the River Lym.

The cross-profiles of the valleys show a marked terrace above the Lias, where sapping by springs has worn back the Upper Greensand into a scarp above, locally so precipitous as to be regarded as a "slip-scarp"; while in the interfluve spurs the Upper Greensand shows exceptionally smooth contours. The lower hillsides have irregular knolly contours in the Lower Lias clays and limestones.

Probably the Yawl and Harcombe streams were the earliest to develop, as consequents on the tilted Pliocene plateau surface. As the land rose, the valleys were deepened, sectioning the Cretaceous beds, which in turn supplied springs, until the Jurassic was reached. The Cannington stream forms an obsequent tributary to those of Yawl and Harcombe; its headwaters in the Shapwick valley probably captured the original head in the Happy valley.

The remarkable correspondence between the cliff and valley profiles is due to the fact that the erosion of the cliffs, like that of the valleys, is mainly sub-aerial.

In preparing this account, as in my previous studies of the cliffs near Lyme, I am again deeply indebted to Dr. W. D. Lang, F.R.S., for help, discussion and criticism. I wish also to express my gratitude to Dr. F. B. A. Welch, of the Geological Survey, for certain suggestions, and to Miss Gulielma Lister and the late Mr. C. Wanklyn for information on many topics connected with the Lyme area.

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EXPLANATION OF PLATES 1 AND 2.

PLATE 1.

A.—Horseman's Hill and Cannington valley from north-west ; April, 1942. The precipitous " slip-scarp " of the Upper Greensand overlooks the terrace above the unconformable junction with the Lias clays. This terrace has been utilised by the railway-line, which is seen crossing the valley by a viaduct at Cannington. The valley-bottom shows the irregular contours of the Lias clays, forming rich pasture-land.

B.—Shapwick valley from west ; April, 1938. The smooth slopes of the upper valley-sides, and of the dry valley-floor in the foreground, are cut in Chalk, while the narrower bottom behind is in Upper Greensand. The junction with the Cannington valley, overlooked by the slip-scarp of Horseman's Hill, is seen in the background.

PLATE 2.

A.—Interfluve spur between Pinhay Hollow (to left) and Happy valley at Alder Grove ; April, 1942. The step on the horizon, behind the telegraph pole, is cut in Chalk, while the smooth slope of the spur is in Upper Greensand. The copse of Alder Grove, to the right, grows on swampy ground above the Lias clays.

B.—Knoll Hill and Yawl valley from Woodhouse Hill ; April, 1942. The plateau surface slopes into a prominent interfluve spur in the Upper Greensand. The line of the terrace overlying the clays below is marked by the houses of Yawl. The terrace is heaped with fallen sands and loams. The valley-bottom shows the irregular contours of the Lias and Rhaetic. In the right background, behind the spreading tree, is Uplyme.

FIELD MEETING AT HOOK NORTON AND SIBFORD, OXFORDSHIRE.

Saturday, 15th September, 1945.

Report by T. H. Whitehead, M.Sc., A.R.C.S., F.G.S., and
W. J. Arkell, M.A., D.Sc., D.Phil., F.G.S.

THE party of members left Paddington by the 9.10 train, were met at Banbury by Dr. Arkell, and arrived at Hook Norton at about 11.45, where they were joined by some local geologists.

At Hook Norton station Mr. Whitehead gave a brief account of the geology of the area. The formations to be traversed ranged from the Middle Lias to the Cornbrash. The Middle Lias, or Marlstone, Rock-bed was worked as an iron ore and the ironstone field could be fairly closely delimited by the change in the Rock-bed from an " ironstone " with 20 per cent. or more of iron (the average being about 25 per cent.) and very little detrital matter to a merely impure sandy limestone, this change usually taking place in a comparatively short distance. At Hook Norton they were not far from the western margin of the ironstone field. The field was characterised by narrow belts of somewhat disturbed strata separating much broader areas in which there was very little disturbance. The disturbed belts were in many cases bounded by a pair of faults forming a trough. One such trough, running nearly east to west, ended by the meeting of the two faults at Butter Hill, which could be seen about half a mile to the east of the station.

The party then proceeded to Redlands Quarry, which was visited by kind permission of the Brymbo Steel Company Ltd. On the way in attention was called to some disused gas-fired kilns, which were formerly used for calcining the iron ore before sending it to the furnaces. These kilns had sometimes been mistaken for blast furnaces. Mr. Whitehead explained that, actually, there were not, and never had been, any blast furnaces in this ironstone field, all the ore being sent away to Staffordshire, South Wales and elsewhere for smelting.

On entering the quarry it was found that a new face had been recently developed in the south-east corner. This provided a very good section of the Rock-bed, with the basal limestone of the Upper Lias resting upon and more or less welded to it. This limestone is very fossiliferous and from ammonites collected from it it appeared to belong to the Serpentinum Zone. The lowest zone of the Upper Lias was thus missing, due, it was believed, to an overlap from east to west. East of the Cherwell valley the sequence was more complete and included the " Transition " or " Acutum

Bed," which was absent at Hook Norton. The ironstone in the face here examined, having a cover of Upper Lias, was largely in the green, unweathered condition. Mr. Whitehead explained that the iron minerals were the silicate, chamosite, occurring largely as ooliths, and the carbonate, siderite. The unweathered ore is calcareous and self-fluxing. Weathering oxidises the iron compounds to limonite and reduces the lime-content, thereby increasing the percentage of iron. The quarrying of the ironstone in this field is a considerable industry, the output during the war of one quarry having reached about 1,000,000 tons per annum.

It was found that quarrying had ceased at the north-western face of Redlands Quarry, and that certain features it had been hoped to see were no longer visible. Accordingly a pause was made for lunch in the comparative shelter of a rick-yard.

After lunch the party proceeded across country to Sharp's Hill quarry. On the way Mr. Whitehead pointed out the position of the fault forming the southern boundary of the Stour valley trough. Near Fodge Farm was seen a small quarry in rock identified by Dr. Arkell as Great Oolite White Limestone, faulted down within a few yards of the Lias.

Sharp's Hill quarry has been described in detail by E. A. Walford (1906) and L. Richardson (1911). Most of the beds could still be recognised. Modest recent quarrying had placed a pile of highly fossiliferous *Exelissa* and *Nerinea* limestones handy for the collector. It was suggested by Dr. S. E. Hollingworth that the steep dip of the Hook Norton Beds at the north-eastern edge of the quarry might be due to valley bulging.

From Sharp's Hill quarry the party walked east along the road for half a mile to the upper end of Temple Mills quarry, which now extends from the lower road near the mill to the upper road, a distance of a third of a mile. The beds dip north all the way into the axis of the trough, which must run near the northern edge, under or north of the mill. Dr. Arkell distributed typewritten descriptions of the Sharp's Hill and Temple Mills quarries. The latter is one of the best sections of the upper Great Oolite Series in Oxfordshire, and as it has not been previously described, the following account is now recorded.

TEMPLE MILLS QUARRY, 1 mile S.W. of Sibford Ferris.

	Ft.	ins.
KEMBLE BEDS.		
9. Forest Marble : typical brown, ripple-marked, sandy, flags and dark oyster limestone with many shaly partings, passing laterally into marl and clay. Up to	12	0
8. Upper Epithyris Bed : marl, locally compacted, passing north into limestone ; many *Epithyris oxonica*	1	0
WHITE LIMESTONE (Beds 2-7 = Fimbriata-Waltoni Beds of S. Oxon.)		
7. Limestone, weathering crumbly. O at south end to... ...	1	4

		Ft.	ins.
6.	Bladonensis bed ; cream cheese limestone full of *Aphanoptyxia bladonensis*, *Gervillia waltoni*, *Astarte fimbriata*	3	0
5.	Oyster bed : marl full of *Ostrea hebridica*		6
4.	Green clay, becoming purple and black downwards, with white pellets and lignite ; channelling the beds below to rest locally on bed 1. 0 to	1	6
3.	Argillaceous limestone, blue-hearted, of flinty appearance, in up to six layers with marl partings. 0 to	1	3
2.	Cast bed : greenish marly limestone passing into marl, locally a mass of casts of same fossils as in bed 6 ...	1	0
1.	White limestones with *Nerinea eudesii* and many lamellibranchs ; in bottom course, *Ptygmatis bacillus* and corals	7	0

Bed 4, the dark green, purple and black clay, is similar to and can probably be correlated with a widespread bed in South Oxfordshire, in which the *Cetiosaurus* bones occurredat Bletchingdon and Kirtlington. Bed 2 corresponds with the Bladonensis bed of Eton College pit, Asthall, bed 12, and Fisher's Gate limekiln, North Leigh, bed 4, and of Bladon, bed 6 (Arkell, 1931).

Bed 6 corresponds with the upper Bladonensis bed of Eton College pit, Asthall, bed 14. Bed 8 is then on the horizon of the Upper Epithyris bed of the Cherwell valley (Kirtlington Cement Works, bed 11).

Numerous Echinoid tests were collected on the floor of the Temple Mills pit ; all those sent by Dr. Arkell to Professor H. L. Hawkins were kindly identified by him as *Acrosalenia pustulata* Forbes. Their horizon remains to be determined.

Lower Cornbrash occurs as a small unmapped outlier in the field immediately east of the quarry. The outlier is 12 miles from the nearest point on the main outcrop, near Tackley. Its survival is due to lowering in the Stour valley trough.

A bus met the party at Temple Mills and conveyed them by way of Sibford Gower to Banbury, where tea had been arranged. After tea a vote of thanks to the Directors was proposed by Dr. L. R. Cox. Members then walked to the station to catch trains to London and Oxford.

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PROBABLE SPONGE EMBRYOS IN A ROCK OF ARENIG AGE.

By ALAN WOOD, Ph.D., F.G.S.

COLLOPHANITE pebbles in the manganese ore of Rhiw in the Lleyn peninsula have already yielded many dissociated sponge spicules to Dr. A. W. Woodland.[1] Problematical bodies occurring with these spicules were submitted to the writer, since it seemed possible that they might be of algal affinities.

The rock in which these bodies occur is clearly of unusual origin. Rounded pebbles of collophanite, with calcite, epidote, chlorite and mica are associated with psilomelane (Woodland, *op. cit.*). The sponge spicules of varied form, possibly derived from both Hexactinellid and Tetractinellid types, are imbedded in the collophanite pebbles, their original silica being replaced by a brown mineral of uncertain nature. Associated with the spicules are spherical aggregations of small rounded or subpolygonal bodies (Plate 3, Fig. A). In general appearance these resemble frog-spawn. Though no capsule membrane can be distinguished the bodies appear to be well bound together, for in only one case was their cohesion disturbed. In this specimen (Plate 3, Fig. C) the aggregation appears to have been squeezed and smeared out, the small bodies becoming elongate in form and somewhat dispersed. Another (Plate 3, Fig. B) appears to be contained in a definite membrane. This capsule is larger than those previously described, but the spherical bodies contained within it are much smaller and more numerous. All these bodies, together with the single capsule membrane observed, are now preserved in a brown cryptocrystalline granular material, while the interspaces between the bodies appear to be filled with collophanite.

From the mode of occurrence there can be little doubt that both the larger and smaller bodies were once enclosed within a capsule membrane, and that the whole was soft, easily collapsing and becoming smeared out by pressure. The diameter of the aggregations of larger bodies is about 0.15 mm. on the average, the bodies themselves being of slightly varying diameter with a maximum about 0.02 mm. The larger capsule measures 0.4 mm. across, and the contained bodies vary in diameter from 0.004 to 0.01 mm.

It seems rather probable that these are not the remains of a complete adult organism, but represent some growth stage. The resemblance to mega- and microsporangia is very close, but it is considered unlikely that these bodies belong to the plant kingdom for the following reasons. First, there is no trace of associated plant matter, nor have such reproductive bodies been recorded from

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[1] A. W. Woodland, *Proc. Geol. Assoc.*, vol. 1 (1939), p. 223.

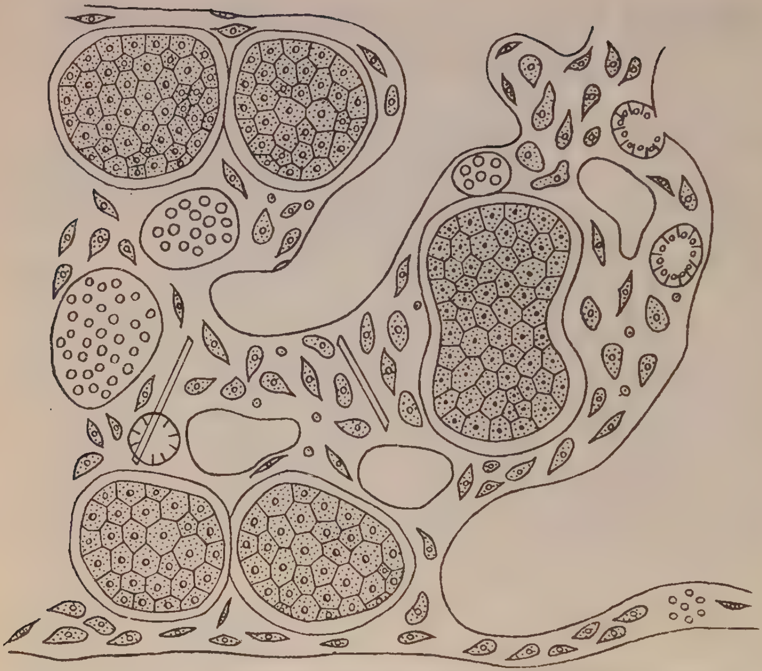


FIG. 6.—SECTION OF *Esperella fibrexilis* TO SHOW DEVELOPING EMBRYOS IN POSITION OF GROWTH.

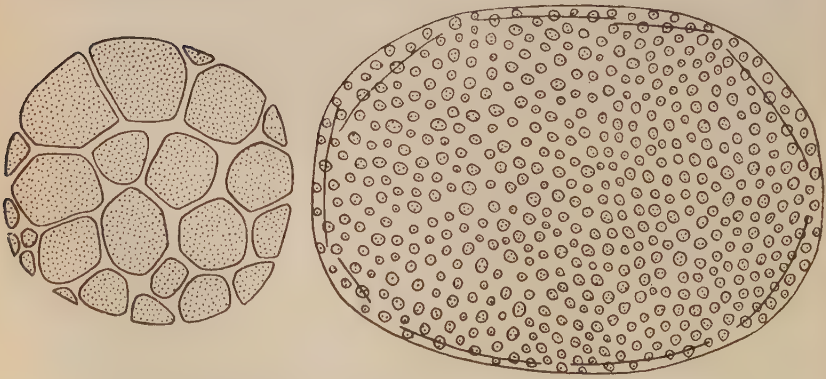
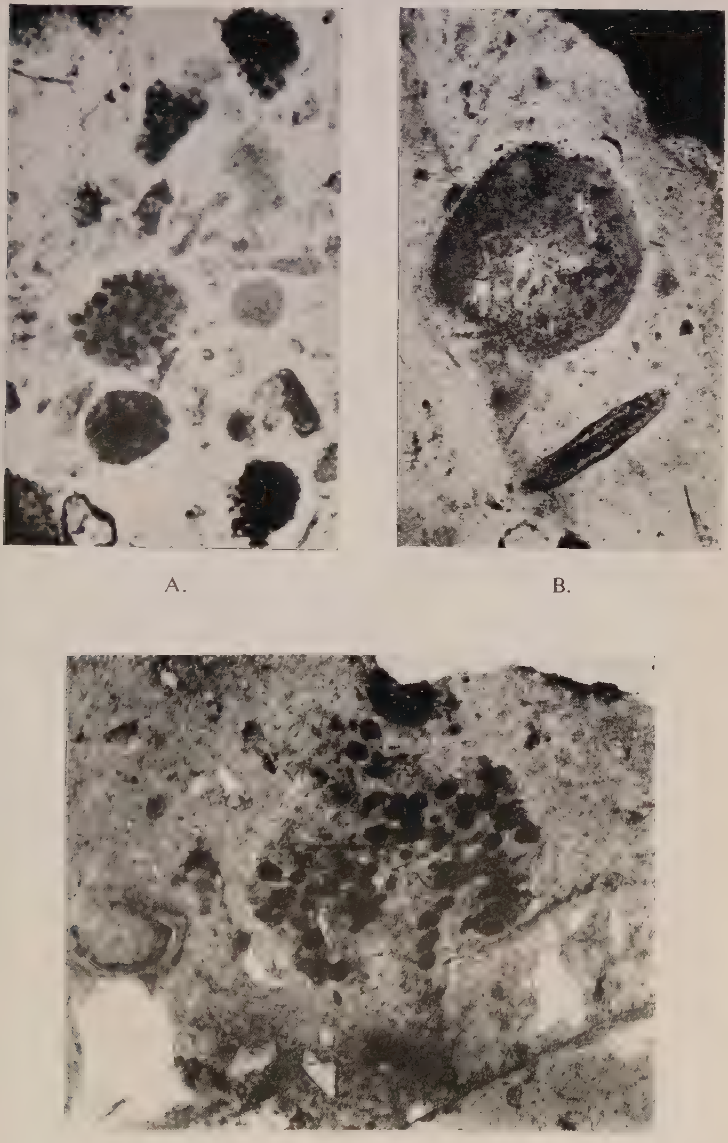


FIG. 7.—EMBRYOS OF *Tedania* sp., RECENT, ANTARTIC. Early stage and later stage to show reduction in size of cells. After Burton 1932.



A.

B.

C.

SPONGE EMBRYOS IN AN ARENIG ROCK.

[*To face p.* 20.

Ordovician rocks, and, secondly, the aggregations resemble closely the embryos of modern sponges, while sponge spicules occur abundantly with them.

The developing embryos of sponges have been described by a number of writers. It appears that in marine sponges at the present day it is impossible to distinguish the embryo resulting from the sexual process from that formed by asexual means, and there is a tendency to restrict the name "gemmule," formerly given to the latter, to the resting stage of the fresh-water Spongillinae. A section of the tissue of *Esperella fibrexilis* (Fig. 6) will serve to illustrate the form of the sponge embryo while still retained within the parent, and will show how closely the segmenting embryo may resemble the capsules of Arenig age. Naturally, since the embryo is segmenting, its size and the number of cells present vary, and this will explain the varying size of the spherical aggregations in the Lleyn rock. The larger capsule with extremely small cells also finds its analogue among sponges at the present day. In species of the genus *Tedania* as figured by Burton[2] the larger cells present in the early stages of the developing embryo are later replaced by a granular mass of smaller cells (Fig. 7). The larger of these embryos is between .2 and .3 mm. in diameter.

Finally, Dr. M. Burton permits me to say that, on boiling a modern Tetractinellid sponge with concentrated nitric acid to obtain the spicules he found that embryos remained behind in the residue, their protoplasm being to all appearance unchanged. The tissue of the parent sponge had been completely dissolved.

It would seem likely, therefore, having regard to this evidence of the resistant nature of some sponge embryos, to the actual association of these fossil bodies with sponge spicules, and their close resemblance in form and size to the embryos of modern sponges, that the bodies here described are true fossil sponge embryos. Preserved in varying segmentation stages by virtue of their somewhat resistant nature, coupled with rapid entombment in a collophanite gel, these specimens must be among the earliest known fossils retaining their cellular structure.

The writer is much indebted to Dr. A. W. Woodland for the privilege of examining these specimens, and to Dr. M. Burton for helpful discussion and for the loan of scarce works on the sponges.

EXPLANATION OF PLATE 3.

FIG. A. Large celled type of sponge embryo, X83.

FIG. B. Small celled type, showing complete capsule and contained cells. X71.

FIG. C. Large type, smeared out and elongated by pressure, X71.

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[2] M. Burton, *Discovery Reports*, vol. vi (1932), p. 237.

MIDLAND GROUP.

FIELD MEETING REPORTS, 1945.

SUTTON PARK

Saturday, 16th June

Director : D. Parkinson, D.Sc., F.Inst.P., F.G.S.

THIS meeting was attended by 26 members of the Group who met at 2.30 p.m. at the bottom of Manor Hill, Sutton Coldfield.

The geology of the district was outlined briefly and the party then walked over the escarpment of the Lower Keuper Sandstone. Its outcrop is limited in this area by the Birmingham fault to the east which throws it against Keuper Marl, and a parallel fault to the west where it is thrown against sandstones and conglomerates of Middle Bunter age. Exposures of Keuper Sandstone showing the characteristic current bedding were examined in and around Wyndley Lane. The western fault was crossed at Wyndley Pool, and the party proceeded through Sutton Park, noticing the hummocky topography characteristic of the Bunter formation.

A halt was made in the disused sandpit at Holly Knoll where pebble beds underlain by a few feet of Permian breccia are faulted against sandstones with scattered pebbles a little higher in the sequence. Neither the breccia nor the fault can now be seen, but Miss Bauer produced a photograph taken on 26th May, 1900, clearly showing the position of the latter.

The party next examined the large gravel pit near Blackroot Pool. Here the Bunter pebbles are of many types, both sedimentary and igneous. They include occasional fossiliferous Lower Palæozoic rocks along with a moderate proportion of Lower Carboniferous cherts. Some of these contain recognisable fossils and a specimen of the coral *Michelinia* was found. Particularly fine examples of pressure pitting were noted among the quartzite pebbles. This quarry has not been used for several years and the eight feet of breccia which was formerly exposed is now covered by scree material from the overlying Bunter.

The walk was continued to Keeper's Pool and in the nearby Bunter gravel pit a small exposure of purple Permian breccia, recently excavated in the quarry floor, was examined. Prof. Wills mentioned that the breccia here is very thin, the swampy nature of the ground and the proximity of a large spring (Keeper's Well) suggesting that the underlying marls come near to the surface.

The party then walked via Powell's Pool to Monmouth Drive where tea was provided by Mrs. Parkinson.

BARNT GREEN AND BROCK HILL PUMPING STATION

Saturday, 18th August

Director : Professor Wills, M.A., Sc.D., F.G.S.

A party of 22 walked from Barnt Green Station to Cattespool Farm. On the way the influence of the Drifts upon the topography of this western edge of the Midland Plateau was pointed out. The sections of water-laid coarse gravel near the Farm is now being worked and numerous erratics of Welsh origin were found. From here members walked to the new Brock Hill Pumping Station of the East Worcestershire Waterworks Co. Ltd. The borings, 612 feet deep, penetrate the Upper Mottled Sandstone and Bunter Pebble Beds.

Here they were met by the Chairman, Alderman Guy Bigwood, and by the Company's Engineer, Mr. F. H. Bullock, B.Sc., and were very hospitably entertained to tea in a specially erected marquee. After tea, three parties were formed to inspect the up-to-date electric pumps and control house, in which were exhibited for our benefit geological sections and core samples from the two wells. Mr. Bullock supplied everyone with typed notes on the installations which were very largely to his own plans. It was agreed that the design of the buildings and the special buff-coloured bricks fitted extremely well into the beautiful rural surroundings.

A return was made to Blackwell Station, but shortage of time prevented members from studying the Triassic rocks as had been projected.

THE LONDON EXCURSION, 1725.

Report by the Director : Dr. John Woodward, M.D.

The document, of which the greater part is here printed, is mentioned at the end of the report on the Field Meeting, "A Walk in West London," published in our *Proceedings*, vol. lvi, Part 4, pp. 231-234. The following selections would have been printed immediately after that report, but for the necessity of keeping within our quota of paper for the year. While Dr. Woodward's excursion is, of course, imaginary, all the pits visited and the objects found thereat are as listed in his catalogues and (as far as possible) are described in his own words; the sites of the pits can mostly be found on Rocque's maps, dated 1746 (for references see Vol. lvi, p. 234). The member who compiled the account wishes to remain anonymous.

C.E.N.B.

MEMBERS assembled at the Pindar of Wakefield, on the north side of Gray's Inn. The early part of the day was devoted to an examination of the brick-clay pits at this place and on the north side of Soho Square, at Tatnam Court, and betwixt Soho and Marybone. The most interesting features of these pits, perhaps, are the various *geodes* or nodules found by the workmen in the clay. These are of two kinds. The larger sort, or Waxen Vein, are commonly round and of a flat or compressed shape. The body of the stone is divided by sparry septa, which grow gradually less in approaching the outside, and sometimes divaricate ; and the tali on each side of the cracks and septa sometimes have *dendritae* or shrubs delineated upon them. The director mentioned that these *geodes* were found also in the tile-clay pits at Kilburn, Islington, and Highgate (on top of the hill), and that he had some in which were immersed great numbers of a sort of *Pectunculus*. From this he deduced that the *geodes* were concreted in water at the time of the Deluge ; that the water, wherewith the pores and interstices were saturated, quitted the bodies during the coalition of the matter, so that they contracted and cracked ; and that in tract of time the cracks were gradually filled with spar insinuated by the water continually pervading the strata.

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A gravel pit on this side Tatnam Court was also visited. Attention was here drawn to nodules of a stone like the puddingstone of Hertfordshire, but worn and smoothed by the motion of water. Pebbles, white with a brown yellow, from the bigness of a horse-bean to that of a nutmeg, are cemented together by a grey flinty matter, with very small red, black, yellow and white spots—perhaps they may be small pebbles. Both the pebbles and the cement take a good polish. Here was a triple process : first the formation of the small pebbles ; next the coalition of the flinty matter that united and cemented them into one nodule ; and finally the rounding of the whole.

Owing to the muddy state of the drift-ways and lanes it was resolved not to ride out to the tile works in the fields near Pancras. Instead the party made west from Marybone until they gained the Edgeware road, where they visited the tile kiln on the left hand side, a short distance before reaching Tyburn toll-gate. The clays used for the making of bricks and tiles all burn red, and doubtless hold some share of iron. There are in them also veins of a bluish marly matter ; and at the Pancras Tile Works very small *selenitae* are found. The class of spars to which these belong have various medicinal uses. An incrusted sort, called *osteocolla*, is used as a conglutinator of broken bones ; a white sort is given in white wine in cases of the stone and nephritic affections ; and also powdered, for the cholic. It was recalled here how after the great storm of 26th-27th November, 1703, when two thousand stacks of chimneys were blown down and practically every roof in London was stripped, the demand for tiles was so great that the price went up from 21s. to 120s. per thousand, and bricklayers' labour rose to 5s. per day.

Entering at the north-east corner by Tyburn turnpike, the party made for the great gravel-pit on the east side of Hyde Park, without the pale. Confronted with so many pebbles of diverse figures and bigness, members persuaded the director to adumbrate somewhat of the origin of the gravel : who spoke as follows. " The gravel about London and in most parts of England is no other than pebbles, or flints, or both, with an intermixture of sand, chiefly of that sort that is composed of extreme little and small pebbles. That sort of sand that is in common use about this town, brought from Blackheath and other parts of this neighbourhood, viewed with a microscope, appears to be nothing but very small pebbles. Whoever shall attentively consider the manner in which this lies in the earth will see that it is not in regular orderly strata, of equal thickness in all parts, as stone lies, and various sorts of earth which are in their original state, and just as they subsided from the waters stagnating at the Deluge. No, this lies in trains, and manifestly pitched in streaks, just as it would be cast by water flowing in its departure towards the ocean and the inlets of the abyss which are at the bottom of it. Gravel is shot and pitched into the same method, and doubtless owes its disposition to the same cause. What adds much confirmation to this is that both are found commonly out of their proper region, cast on lighter matter that is disposed into strata and is in its original state. Thus we see even in this neighbourhood, near Deptford, on other parts of Black-Heath, and in many more places, a great quantity of sand and gravel lying above chalk ; and when we come to dig through perhaps twenty or thirty foot of gravel down to it, we find the chalk lying in regular horizontal strata underneath, down frequently to a very great depth. I have shown what a vast and immense quantity of water there lay on the surface of the globe during the Deluge. And this was not only of mighty bulk and weight, but seems to have passed off in hurry and precipitation. There are pebbles and flints now frequently found among the rest in gravel, that have their surfaces rubbed and smoothed, nay some much ground and worn. All of which was done by the hurry and force of the water, in their removal from place to place."

Amongst the pebbles picked up in this pit was one containing a conic flinty *Echinite*, environed on every side with flinty matter, upon which it had left the impress of its shell, now perished and gone. The director remarked that sometimes these *Echini* are filled with flint, sometimes with chalk. The latter kind are dug up commonly in the great chalk-pits on each side the river at Purfleet, Northfleet and Greenhythe, where the chalk-cutters drive a great trade with the sea-men, who frequently give good prices for these shells, which they call chalk-eggs. The reason they covet them is that the chalk within is of singular purity and fineness; and fine clean chalk is one of the most noble absorbents, most powerfully correcting and subduing acid humours in the stomach, tempering and allaying the emotions and ebullitions of them. This property is what renders it so serviceable in the cardialgia or heartburning, an affection of the upper part of the stomach caused by the ascent of hot acid corrosive steams; and in diarrhœas and fluxes. It has been known to succeed where crabs-eyes, pearl, the cretaceous matter in oyster-shells, and the other testaceous absorbents, availed little. Nor is it less helpful in diarrhœas. Those who frequent the sea, and are not apt to vomit at their first setting forth, fall frequently into loosenesses, which are sometimes long, troublesome and dangerous. In these they find chalk so good a remedy that experienced sea-men will not venture aboard without it.

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From the great gravel pit on the east side, an invigorating canter brought the party to the brick-pit in the fields on the west side of the Park. Here was seen a great heap of nodules of *race*, picked out of the clay by the workmen. They were of several sizes, from the bigness of a pea to that of a hen's egg, but all tuberous and unequal, and most having a red clayey matter within, but some when broken open showing no cavity. A visit was also paid to Kensington gravel pits and the purging spring near by. Accurate enquiries have established that the purging qualities of these waters and of those at Shooter's Hill, Streatham, Dulwick, Epsom, Richmond and Acton, are due to the vitriolic and other salts lying, along with *pyritae*, in the strata through which the waters drain and pass. In a well sunk at these gravel-pits a *Nautilus* was found in a bed of blue clay at a depth of 114 feet. Similar specimens were dug out of the clay at a depth of 60 feet in the clay pit near the wells at Richmond.

Returning by way of Hyde Park Gate, the party examined a gravel-pit amongst the new buildings by Dover Street. The director said that it was in this pit in the year 1688 that he obtained a very peculiar ridged, oval, gritty pebble, which was the first stone he ever took notice of or gathered. Not far away, at another gravel-pit and a tile-clay-pit on the backside of Trinity Chapel, at the end of Bond Street, Piccadilly, members found a bivalve with a most beautiful pearly coat, covering a fine brass-like *pyrites*, and also a number of *Entrocho-Asteriae*. Similar forms occur in the clay-pits on the south side of Islington, and at New Cross, near Deptford.

These pits at Piccadilly concluded the day's round, after which the party (omitting the gravel-pit in St. James's Park, where nothing of interest had been reported) repaired to Brown's Coffee-house, in Kingstreet, Westminster, where refreshments awaited them.

FIELD MEETING IN THE DUSTON DISTRICT NEAR NORTHAMPTON.

Saturday, 7th July, 1945.

Report by the Director : Vernon Wilson, Ph.D., M.Sc., D.I.C.

THE Association has visited this district on three previous occasions—1874, 1891 and 1921. On this occasion the party met at Northampton station and then took the Weedon road out of the town to the old ironstone quarries to the S.E. of Old Duston. Here the Director gave a brief outline of the geology in the vicinity and the Northampton Ironstone was examined in the old quarry face on the north side of the road where 9 to 10 feet of beds are still visible.

The members then proceeded through Old Duston to New Duston where, in the "Top Quarry," the upper Variable Beds of the Northampton Sands with a few feet of overlying white Lower Estuarine Sands were seen and a few fragmentary fossils collected.

The party continued along the road to Harlestone and in a quarry on the west side of the road opposite the lodge at the entrance to Harlestone Heath the following sequence, here recorded for the first time, was examined :—

SECTION IN QUARRY OPPOSITE HARLESTONE HEATH LODGE.

	ft.	ins.
LOWER ESTUARINE SERIES.		
4. Sandy soil with much broken current-bedded brown sandstone in the bottom part	2	0
3. Soft white sand...	5	6
NORTHAMPTON SANDS—VARIABLE BEDS.		
2. Thin current-bedded, flaggy sandstone with occasional lenses of boxstone ; becoming softer towards the base	7	0
1. Thick wedge-bedded brown sandstones with hard, gritty, oolitic lenses in the top 2 feet	13	6

In the next field to the north nearly 30 feet of sandstones belonging to the Northampton Sand Series were seen in a quarry labelled "Clay Pit" on the six-inch map, the details are as follows :

SECTION IN "CLAY PIT" QUARRY, NEAR DUDMAN'S PLANTATION, HARLESTONE.

	ft.	ins.
NORTHAMPTON SANDS—VARIABLE BEDS.		
6. Broken sandstone with sand above	2	0
5. Soft brown ferruginous thin bedded sandstones	5	6
4. Brown sandstones, rather harder than the beds above	2	9
3. Hard, light brown, current-bedded, calcareous sandstone ("Pendle Beds") with limonite partings and "pot-lids" ; the latter are finely oolitic and fissile and are broken up into thin flags for paving and walling	3	9

	ft.	ins.
Dark brown sandstones worked for " cotters " or scouring bricks	10	6
Grey-green-hearted sandstones with dark ferruginous streaks and bands, seen to	5	0

After lunch at Harlestone the party returned to New Duston nd proceeded to the old brick works at Hopping Hill where the Upper Estuarine Clays, containing a massive limestone bed in the upper part, rest non-sequentially on White Sands of the Lower Estuarine Series. The section is now considerably overgrown nd many of the details recorded by L. Richardson (Prof. Cott. F. C., vol. 22, p. 144) could not be made out. However, *Ostrea sowerbyi* and *Placunopsis socialis* were collected from the Upper Estuarine limestone.

About 300 yards to the south of the brickworks the Great Oolite Limestone is exposed in the old disused Limekiln Quarry; most of Mr. Richardson's details of this section (*ibid.*, p. 142) could be made out and numerous fossils were obtained, including a fine palatal tooth of *Lepidotus*.

Near the eastern end of the quarry a temporary excavation had been made in the floor of the quarry and the following details below Richardson's lowest bed (Bed 10) were recorded :—

TEMPORARY EXCAVATION IN FLOOR OF LIMEKILN QUARRY, HOPPING HILL.

GREAT OOLITE.	ft.	ins.
Bed 10 of L. Richardson's section (*ibid.*, p. 142)		
Brown marl parting		1
Dark blue-grey clay	1	0
Soft brown marl		4
Brown silty limestone	1	3
(?) UPPER ESTUARINE CLAYS.		
Blue-grey clays below, seen to	2	0

This concluded the programme of the meeting and on the way back to Northampton a diversion was made to the old village of Dallington where Mr. Greenough, a resident, gave the members some account of the history of the village and its picturesque surroundings. The meeting concluded with an expression of thanks to the Director.

THE ANNUAL REPORT OF THE COUNCIL O THE GEOLOGISTS' ASSOCIATION FOR THE YEAR 1945.

[Adopted at the General Meeting on March 1st, 1946, as the Annual Report of the Association.]

THE numerical strength of the Association on December 31s 1945 was as follows :—

Honorary Members	18
Ordinary Members :—	
Life Members (compounded)	122
Annual Subscribers ...	1160
	1300

During the year 108 new members (a record number) wer elected and two members were reinstated, and the Associatio lost 23 members through death, resignation and other cause Despite the war conditions the membership continues to ris and shows an increase of 87 over that of the previous year.

The list of deceased members is as follows :—J. Archibal F. Chapman, R. M. Deeley, H. Elliott, L. W. Fulcher, W. J. Gibso F. Gossling, D. Keogh, H. P. Nurse, Miss C. A. Raisin, G. W Smith, W. M. Teape, A. Templeman, M. Wilks.

Obituary notices will be found on pages 50–55.

FINANCE.

The Association is in a very sound financial position. Th income from admission fees and annual subscriptions, at £60 shows an increase of £94 10s. over the amount received in 194 and is well above that received in any previous year. The Genera Purposes Account shows an excess of income over expenditure o £27 2s. 7d., which brings the accumulated funds to £163 14s. 8d and, in addition to this, the balances in the various Special Fund available for the general purposes of the Association, excludin the Reserve Fund for Index and List of Members, amount t £298 1s. 9d., an increase of £89 14s. 6d. over the amount at th end of 1944. It must be borne in mind, however, that owing t paper restrictions, the cost of the *Proceedings* has been considerabl below the normal during the War period, and a considerabl increase in this item of expenditure must be expected when norma conditions return.

TRUST FUNDS.

Two awards of £7 each were made from the Foulerton Award Fund, and the balance remaining in the Fund at the end of the year was £13 11s. 8d.

The balance of a grant of £25 made in 1940 from the G. W. Young Geological Investigation Fund has now been paid, but no new grants were made during the year. Owing to a misinterpretation by the Public Trustee of the Provisions of the Finance Act, 1941, the income of the fund was overpaid in the years 1941-1944, with the result that no income was received in 1945, and only a small sum will be payable in 1946. The balance in the Fund at the end of the year was £60.

A donation of £375 was received during the year to establish a new Trust Fund in memory of the late Henry Stopes, the prehistorian.

ACCOUNTS FOR THE YEAR ENDING DECEMBER 31ST, 1945.

GENERAL PURPOSES ACCOUNT.

INCOME.

	£	s.	d.	£	s.	d.
To Admission Fees—						
Received for 1945 Elections	45	0	0			
Received for Arrears	3	0	0			
	48	0	0			
Less Arrears at December 31st, 1944, £4, estimated to realise	2	0	0			
	46	0	0			
Add Arrears at December 31st, 1945, £9 10s., estimated to realise	7	0	0	53	0	0
To Annual Subscriptions :—						
(1) Received in 1943 for 1945	1	10	0			
(2) Received in 1944 for 1945	50	0	0			
(3) Received in 1945 for 1945	402	0	0			
(4) Received in 1945 for arrears	84	10	0			
	538	0	0			
Less Arrears at December 31st, 1944, £359, estimated to realise	40	0	0			
	498	0	0			
Add Arrears at December 31st, 1945, £358 10s., estimated to realise	50	0	0	548	0	0
,, Sale of Publications				11	16	9
,, Miscellaneous receipts					1	8
,, Transfer from other Accounts :—						
From Illustrations Fund Account (for Illustrations)	40	0	0			
,, Compounding Fund	50	0	0	90	0	0
				£702	18	5

EXPENDITURE.

	£	s.	d.	£	s.	d.
By "Proceedings" of the Associations (Vol. LV, Part 4, and Vol. LVI, Parts 1-3)						
(1) Printing	303	18	9			
(2) Illustrations (a) Blocks and Plates ..	25	12	6			
(b) Printing	27	2	0			
(3) Authors' separate copies	15	18	0	372	11	3
,, Printing Monthly Circulars				40	3	0
,, Miscellaneous Printing				3	10	0
,, Stationery				39	1	11
,, Expenses at Meetings				34	15	0
,, Expenses at Field Meetings				1	0	6
,, Addressing and Stock-keeping				38	2	9
,, Postages				93	7	0
,, Insurance					12	3
,, Incidental Expenses				12	12	2
,, Yearly transfer to Reserve Fund for Index and List of Members				40	0	0
,, Excess of Income over Expenditure				27	2	7
				£702	18	5

BALANCE SHEET, DECEMBER 31st, 1945.

LIABILITIES.

	£	s.	d.	£	s.	d.
To Annual Subscriptions received in advance :—						
In 1943 for 1946	1	10	0			
In 1944 for 1946	2	0	0			
In 1945 for 1946	62	0	0			
In 1943 and 1944 for 1947	1	10	0			
In 1945 for 1947	3	0	0			
In 1944 for 1948-51	2	0	0			
In 1945 for 1948-49	1	10	0			
				73	10	0
,, Cash received for Admission Fee and 1946 Subscription before election				1	0	0
,, Sundry Creditors						
Messrs. Benham & Co. Ltd.				4	10	0
,, Special Funds :—						
Illustrations Fund	15	3	3			
Illustrations Fund (Capital)	20	0	0			
Reserve Fund for Index and List of Members	88	0	0			
Compounding Fund	1,734	7	5			
Bequest Funds	802	15	8			
				2,660	6	4
				2,739	6	4
Accumulated Funds at January 1st, 1945	136	12	1			
Add Excess of Income over Expenditure for the year	27	2	7			
				163	14	8
				£2,903	1	0

ASSETS.

	£	s.	d.	£	s.	d.
By Investments (Special Funds) at cost or value when acquired :—						
Bequest Funds—						
£143 8 9 3½% War Stock, at value when acquired	141	14	0			
£150 New Zealand 3¼% Stock 1960/64, at value when acquired	122	5	0			
£285 3% Defence Bonds, at cost	285	0	0			
£100 3% Savings Bonds 1960/70, at cost	100	0	0			
				648	19	0
Compounding Fund—						
£1,217 2 6 Nottingham Corporation 3% Irredeemable Stock, at cost	1,152	13	2			
£200 3% Savings Bonds, 1955/65, at cost	200	0	0			
£170 3½% War Stock, at cost	152	14	5			
£100 3% Savings Bonds, 1965/75, at cost	100	0	0			
				1,605	7	7
Illustrations Fund (Capital)—						
£21 0 10 Metropolitan Water Board 3% B Stock, at cost				20	0	0
,, Annual Subscriptions in Arrears, £358 10s., estimated to realise				50	0	0
,, Admission Fees in Arrears, £9 10s., estimated to realise				7	0	0
,, Cash at Bankers and in hand :						
At Bankers	154	16	4			
In Office	30	18	4			
				185	14	8
,, Special Funds :						
Illustrations Fund at Bankers	15	3	3			
Compounding Fund at Bankers	128	19	10			
Reserve Fund for Index and List of Members at Bankers	88	0	0			
Bequest Funds at Bankers	153	16	8			
				385	19	9
				£2,903	1	0

SPECIAL ACCOUNTS.

ILLUSTRATIONS FUND.

	£	s.	d.
To Balance in hand on January 1st, 1945	7	16	9
,, Donations and Subscriptions	46	14	0
,, Transfer from Illustrations Fund (Capital)		12	6
	£55	3	3

	£	s.	d.
By Transfer to General Purposes Account for Illustrations	40	0	0
,, Balance December 31st, 1945, at Bankers	15	3	3
	£55	3	3

SPECIAL ACCOUNTS (*continued*).

ILLUSTRATIONS FUND (CAPITAL).

		£ s. d.		£ s. d.
To Balance in hand on January 1st, 1945		0 0 0	By Transfer to Illustrations Fund	12 6
„ Dividends as received :—			„ Balance December 31st, 1945	0 0 0
£21 0 10 Metropolitan Water Board 3% B Stock		12 6		
		£0 12 6		£0 12 6

COMPOUNDING FUND.

		£ s. d.		£ s. d.
To Balance in hand on January 1st, 1945		76 12 4	By Transfer to General Purposes Account	50 0 0
„ Composition Fees received during the year		51 10 0	„ Balance December 31st, 1945, at Bankers	128 19 10
„ Dividends as received :—				
£1,217 2 6 Nottingham Corporation 3% Stock	36 10 2			
£170 0 0 3½% War Stock	5 19 0			
£300 0 0 3% Savings Bonds	8 8 4			
		50 17 6		
		£178 19 10		£178 19 10

RESERVE FUND FOR INDEX AND LIST OF MEMBERS.

	£ s. d		£ s. d.
To Balance in hand on January 1st, 1945	48 0 0	By Balance December 31st, 1945, at Bankers	88 0 0
„ Yearly Reservation for 1945	40 0 0		
	£88 0 0		£88 0 0

BEQUEST FUNDS.

		£ s. d.		£ s. d.
To Balance in hand on January 1st, 1945		133 18 2	By Balance December 31st, 1945, at Bankers	153 16 8
„ Dividends as received :—				
£143 8 9 3½% War Stock	£5 0 6			
£150 0 0 New Zealand 3½% Stock	5 5 0			
£285 0 0 3% Defence Bonds	6 13 0			
£100 0 0 3% Savings Bonds 1960/70	3 0 0			
		19 18 6		
		£153 16 8		£153 16 8

"TRUST" FUNDS.

FOULERTON AWARD FUND.

	£	s.	d.		£	s.	d.
To Balance in hand on January 1st, 1945	14	16	8	By Award to R. G. S. Hudson, D.Sc., F.G.S.	7	0	0
,, Dividends as received—				,, ,, ,, W. D. Ware	7	0	0
£255 0 0 Southern Railway 5% Guaranteed Preference Stock	6	7	6	,, Balance 31st December, 1945, at Bankers	13	11	8
,, Income Tax repayment for 1944-1945	6	7	6				
	£27	11	8		£27	11	8

G. W. YOUNG GEOLOGICAL INVESTIGATION FUND.

	£	s.	d.		£	s.	d.
To Balance in hand on January 1st, 1945	80	0	0	By Grants paid in 1945	20	0	0
,, Income Tax repayment for 1944	10	0	0	,, Income Tax recovered for 1944, repaid to Public Trustee	10	0	0
				,, Balance 31st December, 1945, at Bankers	60	0	0
	£90	0	0		£90	0	0

HENRY STOPES MEMORIAL FUND.

	£	s.	d.		£	s.	d.
To Donation to establish Fund	375	0	0	By Balance 31st December, 1945, at Bankers	375	0	0
	£375	0	0		£375	0	0

We have compared these statements with the books and accounts presented to us and find them to agree.

We have also verified the investments of £1,217 2 6 Nottingham Corporation Stock, £200 3% Savings Bonds, 1955/65 £100 3% Savings Bonds, 1965/75, and £170 3½% War Stock of the Compounding Fund, £255 Southern Railway 5% Guaranteed Preference Stock of the Foulerton Award Fund, £143 8 9 3½% War Stock, £150 New Zealand 3½% Stock 1960/64, £285 3% Defence Bonds and £100 3% Savings Bonds 1960/70 of the Bequest Funds, and £21 0 10 Metropolitan Water Board 3% B Stock of the Illustrations Fund (Capital).

E. C. MARTIN, *Treasurer*.

26th January, 1946.

F. W. H. MIGEOD } *Auditors*
G. A. KELLAWAY }

PUBLICATIONS.

Publications Committee. This Committee consisted of the officers (7), together with Mr. T. Eastwood, Dr. A. F. Hallimond, Dr. R. O. Jones, Dr. K. P. Oakley, Dr. R. W. Pocock, Prof. H. H. Read, Dr. Alan Wood, and Mr. A. Wrigley. The Committee met on three occasions and considered fifteen original papers and ten Field Meeting reports. Recommendations regarding these were made to the Council.

The Proceedings. The paper restriction regulations again only permitted the printing of a comparatively small volume. Volume LVI consists of 243 pages, and contains the Presidential Address, ten original papers, twelve field meeting reports, an account of the Annual Reunion, and the Annual Report of Council. The volume is illustrated by ten plates and seven text figures.

MEETINGS.

Ten meetings were held, at which three papers were read, one paper was read in abstract, and four lectures were given. Particulars of these will be furnished later in the Session Report.

The thanks of the Association are due to the Authors and Lecturers. The attendance at meetings was slightly above last year, averaging 66.

The Ordinary and Annual General Meetings were held at the apartments of the Geological Society of London and the Committee meetings at the Imperial College of Science and Technology (Royal School of Mines).

Tea was provided either before or after the Ordinary meetings.

The Association's thanks are due to the respective authorities for the generous facilities afforded.

REUNION.

The Annual Reunion was held at Chelsea Polytechnic on Saturday, 3rd November. A number of interesting exhibits were shown including one by H.M. The King, and the attendance equalled that of pre-war years. Thanks are due to the authorities of the Chelsea Polytechnic, the organisers and the members concerned.

A full account of this meeting will be given in the *Proceedings.*

FIELD MEETINGS.

The Committee consisted of the officers, Miss E. Dix, Messrs. E. P. Bottley, T. Eastwood, W. F. Fleet, K. P. Oakley, A. Templeman and A. Wrigley.

Owing to difficulties in arranging for transport and accommodation, the programme was somewhat curtailed. Fourteen meetings were held as follows : half day, 4 ; evening, 2 ; whole day, 7 ; week end, 1. The average attendance was 26. A number of reports have been published in the *Proceedings*.

The best thanks of the Association are due to Directors and others who organised and assisted in the meetings.

THE LIBRARY.

Although it may not be possible to bring back the greater part of the Library to London until the reconstruction of the destroyed portion of University College, a number of geological text-books and periodicals are now available at the College, where they may be consulted or borrowed by members of the Association. Certain other works can be borrowed by post on application to the College Librarian. In response to an appeal in the December circular several members have presented series of offprints of their papers to the Library. To these and to the donors of a number of other works the Association wishes to record its thanks. A list of gifts to the Library will be published in the *Proceedings*. Exchange arrangements have been resumed with and war-time publications received from a number of institutions on the European Continent.

NORTH-EAST LANCASHIRE GROUP.

Chairman : J. Ranson, A.M.I.M.E., F.G.S.

Joint Secretaries : A. Bray, M.Sc., A.Inst.M.M. (for correspondence) and Mrs. E. J. Harrop, B.A., B.Sc.

During the year four lectures were delivered and one Field Meeting was held.

At the Annual General Meeting the Chairman and Secretaries were re-elected with a new Committee. The thanks of the Group to the Education Committee and the College authorities for the use of rooms in the Blackburn Technical College was proposed and carried.

MIDLAND GROUP.

Chairman : D. Parkinson, D.Sc., Ph.D., F.Inst.P., F.G.S.

Secretary : Miss Grace M. Bauer.

Committee : Professor L. J. Wills, Miss E. M. Hignett, J. A. Best, Miss M. E. Tomlinson, Dr. F. Raw, and Dr. W. O. Williamson.

During the year, four Lecture Meetings were held at the Geological Department, the University, Birmingham, and there were Field Meetings. Particulars will be published in the *Proceedings*. The attendance was well maintained.

Thanks are due to Professor Wills for the use of the Geology Department at the University, Birmingham.

WEALD RESEARCH COMMITTEE.

Progress has been made with some field work, and the Committee has recommenced its meetings. Field Meetings were organised at Tunbridge Wells, Pulborough, and East Malling. A record of temporary sections in the Weald noted by members has been initiated.

TRUSTEES.

The Trustees of the Association are :—

Managing : Mr. F. N. Ashcroft, M.A., F.G.S., F.C.S., F.R.G.S., Mr. S. Hazzeldine Warren, F.G.S., and Dr. W. F. Fleet, M.Sc., A.R.I.C., A.C.P., F.G.S.

Custodian : The Royal Bank of Scotland, Western Branch.

FOULERTON AWARD.

The Foulerton Award for the year was given jointly to Mr. W. D. Ware and Dr. R. G. S. Hudson, F.G.S., for services to geology.

HENRY STOPES MEMORIAL FUND.

The Council records with very great pleasure, the receipt of a sum of money for the establishment of a fund in memory of Henry Stopes, a pioneer in investigations concerning Early Man. The Fund, which is to be known as the Henry Stopes Memorial Fund, will provide for the triennial award of a bronze medal for work on the prehistory of Man and his geological environment.

The conditions governing the Award will be published in the Report of the Session.

HOUSE LIST.

Mr. A. S. Kennard, A.L.S., F.G.S., retires from the office of President after having most zealously served the Association through two of its most difficult years. Miss E. Dix and Mr. C. E. N. Bromehead retire as Vice-Presidents, and Messrs. A. F. Hallimond, M. A. Ockenden, Alan Wood and A. Wrigley, as Ordinary Members of Council. Mr. G. S. Sweeting retires as Editor after 14 years' service ; a record in the history of the Association.

REPORT OF THE SESSION, 1945.

Ordinary Meeting, 6*th January*, 1945.—Mr. A. S. Kennard, A.L.S., F.G.S., President, in the chair.

Arnold Bottomley, John Vernon Buller, John Alfred Cleaver, Sydney Herson, A.M.I.Struct.E., Henry Alan Moisley, B.Sc., Miss Edith Thom Smillie, B.Sc., and John Herbert Walsh were elected Members of the Association.

Messrs. C. T. A. Gaster and G. A. Kellaway were elected to audit the accounts for 1944.

The following paper was read :—" Geology in Embryo," by C. E. N. Bromehead, B.A., F.G.S.

Ordinary Meeting, *3rd February*, 1944.—Mr. A. S. Kennard, A.L.S., F.G.S., President, in the chair.

Robin Gilbert Charles Bathurst, John Stuart Goldsmith, Audrey Arnott Gore, Eileen Mary Pyatt, Frank Trevor Raleigh, Rosemary Sales, Kenneth James Watson, and Leslie Frank Ian Wolters, were elected Members of the Association.

The following lecture was delivered :—" Recent Earth Movements from an Engineering Point of View," by G. B. R. Pimm, M.Inst.C.E.

The following paper was read in Abstract :—" Notes on Some Glacial Features in North-East Derbyshire," by A. C. Dalton.

Annual General Meeting, *3rd March*, 1945.—Mr. A. S. Kennard, A.L.S., F.G.S., President, in the chair.

The Annual Report of the Council (already circulated) was taken as read. It was moved by Dr. Oakley, and seconded by Dr. Vernon Wilson. " That the Report of the Council, including the Statement of Accounts, be adopted as the Annual Report of the Association for 1944." The resolution was carried *nem. con.*

The President declared the following members duly elected as Officers and Members of the Council in accordance with Rule XIII :—President, A. S. Kennard, A.L.S., F.G.S. ; Vice-Presidents, Miss Emily Dix, D.Sc., F.G.S., C. E. N. Bromehead, B.A., F.G.S. ; Professor H. H. Read, D.Sc., A.R.C.S., F.R.S., F.G.S., R. W. Pocock, D.Sc., F.G.S., T. Eastwood, A.R.C.S., F.G.S. ; Treasurer, E. C. Martin, B.Sc., A.I.C., F.G.S. ; Secretaries, General—R. Reeley, F.G.S., Field Meetings—G. W. Himus, Ph.D., M.I.Chem.E., F.G.S., Publications Committee—A. J. Bull, Ph.D., M.Sc., F.G.S. ; Editor, G. S. Sweeting, D.I.C., F.G.S. ; Librarian, L. R. Cox, M.A., Sc.D., F.G.S. ; twelve other Members of the Council, E. P. Bottley, F.G.S., L. J. Chubb, Ph.D., M.Sc., F.G.S., W. Dack, I.S.O., F.G.S., A. F. Hallimond, M.A., Sc.D., F.G.S., C. T. A. Gaster, F.G.S., Capt. F. Jones, T.D., Ph.D., M.Sc., F.G.S., A. T. Marston, L.D.S., F.G.S., M. A. Ockenden, F.G.S., M.I.Mech.E., Miss E. White, B.Sc., F.R.G.S., F.G.S., Vernon Wilson, B.Sc., Ph.D., D.I.C., F.G.S., Alan Wood, B.Sc., Ph.D., F.G.S., A. Wrigley.

It was moved by Mr. L. J. Pitt, seconded by Mr. S. W. Hester, and duly carried, " that the best thanks of the Association be given to the Officers, the retiring members of Council, and the Auditor."

The Foulerton Award was presented to Dr. R. G. S. Hudson, D.Sc., F.G.S., and Mr. W. D. Ware, in recognition of services rendered to the Association.

The President said :—

Dr. R. G. S. Hudson. Since you left London you have followed the geological tradition of your teacher, Prof. Garwood, in the Carboniferous System as developed in the Pennines and the surrounding country and added greatly to our knowledge of its stratigraphy, structure and palæontology. You have acted as principal director of two summer Field Meetings of this Association—in 1933 to the Yorkshire Dales and in 1938 to the Harrogate district, where we had the pleasure of hearing your very stimulating and clear expositions of the Geology of this country, which you know so well and like so much. By your long association as an officer of the Yorkshire Geological Society and as Editor of its *Proceedings* you have helped many amateurs in their often profound contributions to our science—not only have you collected fossils for their study, but you have helped them in the rendering of their results, and I know that you will be the first to admit that you, too, have gained by this. Of your own special discoveries and contributions to palæontology, particularly of the Corals and latterly of the Goniatites, this work is known and used internationally and requires no appraisement from the Association or from me. In handing you this award we know that it goes to an active Geologist and Palæontologist who has deserved well of the science he has served and of this Association.

Mr. W. D. Ware. It was indeed fortunate for Geology that in 1917, when serving in the Army in France, that owing to your mining knowledge you were selected for the task of a new water supply to a R.F.C. camp in the Seine valley by a deep well in the chalk. Accustomed a you were to the deposits in South Wales, you were struck at once by the contrast and determined to know " Why ? " a little word that is the seed of all progress. It also chanced that an English-speaking German prisoner was assisting you in the work and he had studied Geology. From him you had your first lessons in our science. You had passed through the wicker gate and the rough and narrow path of your " Pilgrim's Progress " had begun. Returning to S. Wales after the war your outlook was indeed grim ; a member of a " depressed industry " in a " depressed area," a total lack of books and having no friend from whom you could obtain help. These difficulties would have daunted all men except the very elect. But you persevered ; buying a book now and again, each purchase entailing self-sacrifice, and making rare visits to the Welsh National Museum at Cardiff.

Little by little you surmounted your difficulties in a way that would have gladdened the heart of Dr. Smiles, and the whole story deserves far more publicity than I can give and the title should be " Geology on the dole." The sinking of the Cefn Coed shaft gave you your opportunity, and you quickly seized it with the result that our science was enriched with an epoch-marking account of the beds and their contained fossils, a fine example of " self-help " and of that freemasonry amongst fellow workers which is so characteristic of Geology, as I know by past experience. But for you all this evidence would have been lost. Later, either in collaboration or alone, you have added greatly to our knowledge of both Coal Measures and the Millstone Grit sequences and fossils. But for the war we are certain you would have been leading Field Meetings of this Association to those districts in which you would speak as an authority, but this is only a pleasure postponed. In making this award to you we feel that it is more than deserved, and it is a tribute to your enthusiasm, which needs no incentive to continue the work, for you are a born geologist. I know of no finer example of Trollope's words : " 'Tis dogged as does it."

The President then delivered his address entitled " The Early Digs in Kent's Hole, Torquay, and Mrs. Cazalet."

It was moved by Mrs. Treacher, seconded by Miss Mary Johnstone, and duly carried " That the President's Address be printed and circulated among the members."

Ordinary Meeting, *3rd March*, 1945.—Mr. A. S. Kennard, A.L.S., F.G.S., President, in the chair.

Morgan James Barber, Frank David Beasor, Eric Fred Blackbourn, A.M.Inst.C.E., A.M.Inst.W.E., Annette Constance Daphne Brading, Ann Pamela Conolly, Major Percy Evans, A.M.I.E.E., George Frederick Mugele, B.Sc., A.M.Inst.C.E., A.M.Inst.W.E., Ronald Frederick William Redman, John Stewart Roberts, and William Abraham Hyman Welsman, were elected Members of the Association.

Ordinary Meeting, *6th April*, 1945.—Mr. A. S. Kennard, A.L.S., F.G.S., President, in the chair.

Richard Chown, Peter Coxhead, Robert Henry Cummings, Geoffrey Arthur William Dove, Miss Helen Gertrude Everton-Jones, Henry John Green, O.B.E., M.C., M.Inst.C.E., Winifred Miers Hooper, John Coningsby Myott, Miss Olive Antoinette Pimm, Alec Ferens Snaith, and John Stuart Webb, A.R.S.M., B.Sc., F.G.S., were elected Members of the Association.

The following lecture was delivered :—" Opencast Mining of Ironstone and Coal," by W. D. Evans, Ph.D., M.Sc., F.G.S.

Ordinary Meeting, *4th May*, 1945.—Mr. A. S. Kennard, A.L.S., F.G.S., President, in the chair.

Robert Edmund Blackith, Alexander Bremner, George Darlow, Frank Bell Kelly, and Miss Ruth Elizabeth Marks, were elected Members of the Association.

The following lecture was delivered :—" Mining Geology of Cornwall and Devon," by H. G. Dines, A.R.S.M.

Ordinary Meeting, *1st June*, 1945.—Mr. A. S. Kennard, A.L.S., F.G.S., President, in the chair.

Lt.-Col. George Adam Beazeley, D.S.O., James Charles Brind-ey, M.Sc., F.G.S., Miss F. Winifred Dore, B.A., John Weller Sandford Fawcett, M.Inst.C.E., F.G.S., Derek Hawkes, Henry Houston, Miss Eileen Mary McGarry, B.A., F.R.G.S., George Frederick Oxtoby, Cecil Robinson, and Ewen Williams-Mitchell, were elected Members of the Association.

The following paper was read :—" Some Physical Features of he Dolgelly District," by Professor A. Austin Miller, D.Sc., F.R.G.S.

Ordinary Meeting, *6th July*, 1945.—Mr. A. S. Kennard, A.L.S., F.G.S., President, in the chair.

Bertram George Fletcher Adlington, George Bisson, Henry Forster Dickie, John Ronald Doulton, Ernest Neil Kitson, Peggy Willis Lambert, B.Sc., Peter Robinson, Horace Sanders, Herbert Gordon Stock, Miss Mary Aline Watson-Jones, B.A., and Herbert ames Whitbread, were elected Members of the Association.

The following paper was read :—" The Terraces of Bournemouth," by J. F. N. Green, B.A., F.G.S.

Ordinary Meeting, *3rd November*, 1945.—Mr. A. S. Kennard, A.L.S., F.G.S., President, in the chair.

Norman Alfred Barnes, Jan Willem Bausch von Bertsbergh, D.Sc., Lionel Edgar Holloway, F.G.S., John Edward George Mosby, Norman Berry Peake, Harold Montague Sale, Geoffrey Wells Smith, Haydn Rankin Taylor, Leslie Willis, were elected Members of the Association.

The re-union was then held in the Large Hall, Chelsea Polytechnic. For list of exhibits see below.

Ordinary Meeting, *7th December*, 1945.—Mr. A. S. Kennard, A.L.S., F.G.S., President, in the chair.

Douglas Wilfred Blackmore, A.M.Inst.C.E., Montague Ian Blazey, Cecil John Sidney Bromfield, F.R.A.S., John McGarva Bruckshaw, Ph.D., M.Sc., D.I.C., F.Inst.P., John Russell Butler, Arthur Cedric d'Agnall Clutterbuck, Kenneth Cross, Blanche Dorothy Eva Day, Colin David Fielder, Edward Howel Francis, Arthur Bernard Goggs, Brian Stephen Gossling, Emile Andre William Rouyer Guillet, Brian William Haines, Robert John Cecil Harris, A.R.C.S., B.Sc., Ph.D., A.R.I.C., William Heap, Lionel Hugo Kemp, B.Eng., Simon Kornbluth, Jack Herbert Lavender, Margery Patricia Forbes Marsden, Frederick Owen-Smith, F.G.S., William Paterson, John Philbin, Stanley Albert John Pocock, William Hubert Craven Ramsbottom, William Herbert Ebenezer Rivett, Bryan Paul Ruxton, Derek Lawrence Searle, Prof. Louis Bouvier Smyth, M.A., Sc.D., M.R.I.A., John Henry Tweedie Stilgoe, Olwyn Daphne Suggate, B.A., Tom Willits, Joan Eveleen Mary Sylvester Bradley, M.A., F.R.G.S., Gwyn Thomas, Becket Whitehead, Bernard Charles Worssam, Charles Edmond Worthington, L.R.I.B.A., M.I.Struct.E., were elected Members of the Association.

The following lecture was delivered :—" Terrestrial Heat and Earth Movements," by A. J. Bull, Ph.D., F.G.S.

LIST OF EXHIBITS.

His Majesty, The King.

Two bound volumes of contemporary paintings and drawings of geological specimens in the museum of the Lincei Academy at Rome in the early seventeenth century.

The President.

Geological " Bygones."

The Geological Survey and Museum.

Maps and diagrams illustrating the war-time work of the Geological Survey and Museum on bedded ironstones, open-cast coal production and underground water-supply.

Photographs illustrating the occurrence, mining and treatment of certain West of England vein-minerals and ball-clays.

Chelsea Polytechnic, Department of Geology.

Specimens collected during field work in Shropshire.

Bottley, E. P.

Crystallised Golds from the Rezende Mine, S. Rhodesia.

Fluorescent calcite groups from a new Cumberland locality.

Devonian fossil fish from a new quarry in Caithness.

Fine minerals, including an exceptional Autunite from Portugal and other Uranium-bearing and radio-active specimens.

Bromehead, C. E. N.

Specimens and contemporary books for comparison with His Majesty's albums.

Casey, R.

Fossil discoveries in the Folkestone Beds of the Lower Greensand.

Some unrecorded and undescribed genera and species.

New light on the evolution of the Cretaceous Inocerami.

Chubb, L. J.

Specimens of Aberystwyth Grits showing (a) Graded Bedding, and (b) Contorted Bedding, both the upper and lower contacts of the contorted bed being visible.

Seven block models illustrating the development of drainage and topography in an area of evenly dipping beds.

Eight block models illustrating the development of drainage and topography in an area of folded beds.

Sweeting, G. S., and Himus, G. W.

Maps and specimens illustrating the geology of the Ashover District, Derbyshire.

Tomkinson, P. B. (per C. E. N. Bromehead).

Engraved lead plaque showing the Conduit House near Hyde Park Corner, made from the lead of the original pipes.

Toombs, H. A.

The use of acetic acid in the development of vertebrate fossils.

Venables, E. M., and Turner, J. G.

Fossils from the London Clay of Bognor Regis, collected during 1945.

Wood, Alan.

A false interference-figure.

Wright, C. W., and Wright, E. V.

Some interesting Albian Ammonites from Bedfordshire and Surrey.

New Species of Crabs from the Albian "Shenley Limestone."

Cretaceous Fossils from North-West Germany—the "Fruits of Occupation."

Wrigley, A.

Fossils from the Blackheath Beds in the Rock Pit at Elmstead Woods, and from the London Clay, etc., of London air-raid shelters.

FIELD MEETINGS, 1945.

Conditions remained difficult ; accommodation was hard to obtain and, until June, the Government ban on the use of local transport remained, consequently it was impossible to hire motor coaches and meetings were restricted to areas which were within easy walking distance of a railway station. Although it had been hoped to arrange for a long week end in the Matlock district at Easter and for a week or ten days at or near Sedbergh in August, the meetings had to be abandoned for the reasons given above.

The following meetings took place :—

Saturday, 5th May.—Despite bad weather, a party of 30 members and guests enjoyed a half-day in the neighbourhood of Pangbourne, under the direction of Professor Hawkins.

Saturday, 12th May.—Dr. H. Dighton Thomas and Major C. W. Wright conducted a party of 30 to the Gault pit at Dunton Green and to a section in Hythe Beds at Dryhill, where a striking double anticline with intervening syncline was exposed.

Wednesday, 16th May.—A "Walk Round London," from Charing Cross to Kensington Gardens was led by Mr. C. E. N. Bromehead in the evening. Forty members of the Association attended, and the strength of the party was augmented by a number of casual "hangers-on" who attached themselves en route.

Saturday, 26th May.—Mr. S. E. Coomber directed a half-day meeting to Redhill to visit sections in the Folkestone Sands and Sandgate Beds, the party numbering 27.

Saturday, 2nd June.—A party of 24, under the direction of Dr. G. H. Mitchell, visited the open-cast workings of coal in the neighbourhood of Polesworth, Warwickshire.

Saturday, 9th June.—The meeting which had been deferred from 10th June, 1944, took place, and Mr. G. S. Sweeting, with a party of 16, made a traverse through the Weald from Southborough to Eridge.

Saturday, 23rd June.—Eighteen members and friends spent an interesting day in the Pulborough district, under the direction of Dr. A. J. Bull. It had been hoped that Mr. J. F. Kirkaldy would be present as co-director, but prior claims on his time prevented him from taking part.

Saturday, 7th July.—A party of 30 was conducted by Dr. Vernon Wilson to examine the Northampton Sands Ironstone, and the strata above the Great Oolite in the neighbourhood of Northampton.

Wednesday, 11th July.—Miss E. Dix led a number of members in a visit to the classic section at Charlton. The party was limited to 15.

Saturday, 14th July.—Mr. F. H. Edmunds took a party numbering 30 to the Mole Valley, from Leatherhead to Dorking.

Saturday, 21st July.—Thirty-one members, directed by Miss E. Dix and Major C. W. Wright visited Guildford and the Guildford-Godalming By-Pass, where they examined the workings of the Dorking United Brick Co. and the sections in Chalk displayed in the side of the by-pass road.

Saturday, 28th July.—A visit was paid during the afternoon to the Rock Pit at Elmstead Woods, under the direction of Mr. A. Wrigley. There were 21 in the party.

Friday, 31st August to Sunday, 2nd September.—This was the nearest approach to a " long " field meeting which took place. Drs. R. W. Pocock and G. H. Mitchell and 30 members and visitors spent a long week-end at Wellington, with two days in the field.

Saturday, 15th September.—Mr. T. H. Whitehead and Dr. W. J. Arkell led a meeting comprising 30 members and visitors to Hook Norton and Sibford, Oxfordshire. This meeting was noteworthy in that it was possible to hire transport, the Government ban having been lifted. The booking of the bus, which saved the party a five mile walk at the end of the day, was effected the day after the restrictions came to an end.

Saturday, 29th September.—This meeting had originally been planned to take place on Sunday, 2nd October, 1939, and was only carried out after a delay of very nearly six years. Dr. G. W. Himus led a party of 19 on a traverse from Barming station to East Malling to study the local features of the Lower Greensand.

Although the Field Meetings Committee set out with the hopes of arranging a more or less " normal " programme in 1945, these hopes were quickly shattered by the difficulties already alluded to. Nevertheless, in some ways 1945 represents an improvement on

1944, and the best thanks of the Association are due to the Directors and to all who so willingly took part in the organisation of the meetings, often in the face of abnormal difficulties.

NORTH-EAST LANCASHIRE GROUP.

The following Meetings and Field Meetings were held during 1945 :—

24th February.—Lecture, " The Geology of Upper Ribblesdale," by T. Entwistle, B.Sc.

23rd March.—Chairman's Address, " Lake District Studies," J. Ranson, F.G.S.

27th June.—Field Meeting : Outcrop workings near Wigan, Leader : A. Bray, M.Sc., A.I.M.M.

7th July.—Field Meeting : Black Hill and Sabden. Leader : J. Ranson, F.G.S.

26th October.—Lecture, " Geology of the Lake District," by J. Ranson, F.G.S.

30th November.—Lecture, " Erosion surfaces in Southern England," by J. Millward, M.A.

13th December.—Lecture, " The Thames Valley," by W. Ashworth, F.G.S.

MIDLAND GROUP.

The following Meetings and Field Meetings were held during 1945 :—

24th February.—Lecture, " The Sub-Mesozoic floor of the southern part of England," by Professor L. J. Wills, M.A., Sc.D., F.G.S.

28th April.—Lecture, " Goniatites," by W. S. Bisat, F.G.S.

16th June.—Field Meeting : Sutton Park. Leader : Dr. Parkinson, F.Inst.P., F.G.S.

18th August.—Field Meeting : Barnt Green and Brock Hill Pumping Station. Leader : Prof. L. J. Wills, M.A., Sc.D., F.G.S.

10th November.—Lecture, " Problems in the Lower Carboniferous of the North Midlands," by Dr. Parkinson, F.Inst.P., F.G.S.

8th December.—Lecture, " The chemistry of Gemstones," by Prof. Gordon, M.A., D.Sc., F.R.S.E., F.G.S.

DONATIONS TO THE LIBRARY DURING THE YEAR 1945.

ARKELL, W. J.—" The Zones of the Upper Jurassic of Yorkshire " (1945) and 24 other pamphlets.

BRAY, A.—" The Carboniferous Sequence between Lothersdale and Cowling (Colne) " (1927) and 4 other pamphlets.

Bull, A. J.—" The Compression of a Sheet " (1943) and 10 other pamphlets.

Dalton, A. C.—" The Doncaster Delta " (1943) and one other pamphlet. Also " The Natural History of the Toronto Region " by J. H. Faull (1913).

Davis, A. G.—" The Lower Carboniferous in a Boring at Alport, Derbyshire " by R. G. S. Hudson, G. Cotton and A. G. Davis (1945).

Evans, I. O.—" Geology by the Wayside " (1940).

Macfadyen, W. A.—" Foraminifera from the Green Ammonite Beds, Lower Lias, of Dorset " (1941) and 13 other pamphlets.

Moore, L. R.—" The Geological Sequence of the South Wales Coalfield : The ' South Crop ' and Caerphilly Basin, and its Correlation with the Taff Valley Sequence " (1945).

Neiva, J. M. Cotelo.—" Jazigos portugueses de Cassiterite e de Volframite " (1944) and 4 other pamphlets.

Stockholm, K. Svenska Vetenskapsakademien.—" Carl Wilhelm Scheele Manuskript 1756-77 " (1942).

Thackeray, Miss R. M.—" The Zones of the White Chalk of the English Coast " by A. W. Rowe. 5 parts (1900-8) separately bound.

Ting Ying (per The British Council).—" Research on the Past Climate and Continental Drift," 3 vols. (1942-3). Published by the author, Yungan, Fukien, China.

HENRY STOPES MEMORIAL FUND.

A sum of money (£375) having been accepted by the Council for the establishment of a memorial to Henry Stopes, the donor and the Council have decided that the money shall be applied and awards made in the following manner :—

1. The die of a medal to be prepared under the direction of the President in consultation with Dr. Stopes, the total cost of which and of the first award shall be defrayed out of the original sum received.
2. The balance of the gift after all liabilities in connection with the preparation of the die and first award have been discharged shall be invested as a trust fund of the Association, the Fund to be called the Henry Stopes Memorial Fund.
3. The income of the Fund thus established and from any future additions to the capital thereof shall be once in three consecutive years at the disposal of the Council for the defrayment of the cost of a medal or medals and for the provision of a gift towards the cost of preparing and delivery of a lecture.

4. The medal to be made of bronze to be called the Henry Stopes Memorial medal and to be awarded for work on the Prehistory of Man and his geological environment, to any member of the Geologists' Association or other person without restriction as to country or sex, preference being given to non-professional work.
5. The medalist to be invited to deliver a lecture to the Association on his work or on some aspect or aspects of the subject thereof and for this lecture he or she shall be given such a sum as the Council may determine, but not less than fifteen guineas, out of the accumulated income available at the date of the award of the medal.
6. The delivery of the lecture shall not be obligatory and if for any reason the lecture be not delivered then the available accumulated income or such part thereof as the Council may determine shall be transferred to the capital of the fund and invested.
7. The lecture shall be called the Henry Stopes Memorial Lecture in announcements and so entitled if published.
8. In the October preceding the year in which an award is due to be made the Council shall appoint a committee to recommend the name of a recipient. The Committee shall consist of the President and four other members of the Association. The President shall be *ex officio* Chairman of the Committee and his decision shall be final on any question of interpretation. If for any reason the President be unable to attend a meeting of the Committee, the members present shall elect a Chairman from amongst themselves. Three shall be a quorum.
9. An announcement stating that the Council is about to make an award shall be published in the printed notices of the next ensuing November and December meetings of the Association; the said announcement shall be read from the chair at the December meeting. The announcement shall contain an invitation to the Membership to submit nominations, and the date fixed for the meeting of the Committee shall also be stated therein.
10. Every member of the Association shall be entitled to nominate one person or two persons jointly. All nominations shall be sent to the Secretary of the Association and no nomination shall be valid unless received by the Secretary before the date fixed for the meeting of the Committee.
11. The Committee shall vote by direct ballot. The names of all duly nominated persons shall be included in the balloting list and voted upon. The Chairman shall be entitled to vote and in the event of an equality of votes shall have a

casting vote. The name of the person who receives most votes shall be recorded as the Committee's selection in its report and the report shall be transmitted to the Council before the next ensuing January meeting of the Council at which the name of the intended recipient shall be decided.

2. In the event of the person selected by the Committee being unacceptable to the Council the names of all duly nominated persons shall be submitted to a direct vote by the Council, in the same manner as that prescribed for the Committee.
3. Two medals for joint work may be awarded on one occasion and a joint invitation to lecture shall be sent ; but only one lecture shall be delivered. In such a case if the lecture delivered be prepared jointly by the medalists the gift shall be divided between them in equal shares, but if that is not the case it shall be awarded to the lecturer.
4. The desire of the Council to offer the award shall be communicated to the intended recipient or recipients in the form of an invitation to accept, and no public announcement shall be made until the award has been accepted. The medal shall be presented at the Annual General Meeting.
5. Dr. Marie C. Stopes shall be invited to nominate the first recipient : thereafter nominations shall be invited in the manner directed, provided only that no member of the Council shall be eligible for the award.

OBITUARY NOTICES.

Frank Gossling, B.Sc., F.G.S., who died at Bristol on 21st June, 1945, aged 86 years, whilst on a visit to his eldest son, was educated at Wolverhampton Grammar School. At school he took many prizes and the first place in geology in the Cambridge Senior Local Examination ; whilst encouraged by one of the masters he won a public competition for a collection of Coal Measure fossils. In 1881 he took his first post, which was with the Inland Revenue, but he continued his scientific studies especially in chemistry, and in a competitive examination obtained a position in the Government Laboratory. At that time the work of the Patent Office was being reorganised and extended, and he obtained fifth place in one of their examinations. In the Patent Office Gossling had a distinguished career dealing particularly with organic chemistry and dyestuffs. During the first German war he was seconded to the Board of Trade and acted as Secretary to Lord Haldane's Committee on the British dyestuff industry. He retired as a Senior Examiner in 1922.

Whilst at the Patent Office, Gossling organised the teaching of organic chemistry at the Birkbeck Scientific and Literary Institution (now the Birkbeck College), where he had himself graduated, and conducted lectures and practical classes for several years with great success. The present writer had the good fortune to be one of his students. Later he was, from 1898 to 1927, a Governor of the College. His many services to the College had already been very appropriately commemorated by the founding of the "Gossling Prize" in geology.

Apart from his studies and official duties, Gossling led an active outdoor life. As a young man he served in the 4th Batt. South Staffordshire Volunteers and shot at Wimbledon for St. George's Vase and Queen's Prize. He cycled in northern France and climbed in Switzerland. On the Association's excursion to the Swiss Alps in 1926 the writer noticed that despite his age Gossling was one of the few who did not fall out for a single day during that fortnight. At the age of 75 he ascended alone the 10,700 ft. Piz Languard at Pontresina, and at 80 climbed to over 9,000 ft. near Saas-Fee.

Frank Gossling's early interest in geology was revived in 1906 when he joined the Association. From then until 1914, partly to interest his children, he did much work in the zoning of the Chalk of S.E. England ; and whilst his results were never published, they have been freely placed at the disposal of later workers. On his retirement in 1922 Gossling began to devote much more time to geology. He studied petrology at the Birkbeck, installed a laboratory in the basement of his house at South Croydon, and on joining the then newly-formed Weald Research Committee he soon became one of its most active members. In his first paper written in 1926 in collaboration with Prof. S. W. Wooldridge " On Outliers of Lenham Beds at Sanderstead, Surrey," it was established mainly by the use of sedimentary petrology that certain sands on the dipslope of the North Downs, first noticed by the late Wm. Whittaker, were of Pliocene age. Then some temporary sections during the construction of a new arterial road aroused his interest n the problems of the Vale of Holmesdale and of the Lower Greensand between Brockham and Westerham. In 1928 he published " The Geology of the Country around Reigate," and in 1934 a report on the River Mole arranged by Mr. J. F. N. Green contained a contribution by him. In 1935 appeared " The Structure of Bower Hill, Nutfield, Surrey," in 1936 a paper on a " High Level Erosion Surface at Oxted," and in 1940 an account of the " Pleistocene Deposits of the Upper Darent Valley." All these contributions were published in our *Proceedings* as Weald Research Committee Reports.

The list of publications may seem small, but their quality was high, for Gossling would never consider publication until he had atisfied himself that he had really completed his work on the problem at issue. He was a master of careful and detailed field work, very carefully and fully recorded, supplemented by thorough petrological examination in his laboratory at home. By using this double line of attack Gossling was able to subdivide the almost completely unfossiliferous Lower Greensand into a series of lithoogical units, which were traceable with certain lateral variations or many miles along the strike. In his most important paper, on Bower Hill, he used his detailed knowledge of the variations of the Hythe Beds to interpret more than 200 auger holes. Due acknowedgment of the valuable assistance given them by Gossling, specially as regards temporary sections, has been made by the uthors of the " Reigate and Dorking Memoir." At the time f his death he had accumulated much data about other problems f the Vale of Holmesdale, and it is hoped that many important bservations will later be made available.

Gossling always examined carefully the geological features of ny district in which he happened to be, and his discovery jointly with one of his sons in 1923 of plant remains on a casual inspection f a roadside quarry in the Old Red Sandstone Senni Beds near Brecon was the direct result of his lifelong habit of careful and horough examination of anything in which he was interested. t was, as it turned out, much against his views that Dr. Heard, who very skilfully worked out the plant remains, described them nder the name of *Gosslingia breconensis* (Heard), *Q.J.G.S.*, lxxxiii, 927, pp. 195-207.

During part of the war Gossling lived at Leeds, and there he made some interesting studies in the geomorphology of the neighbourhood. Returning to Croydon in 1943 he conducted a Field Meeting in May of the following year with the writer. In the winter of 1944-5 he resumed active field work in Surrey, and spent a day in the field with the writer not many days before his death.

His last paper was published on the day he died. It was an account of a temporary section in the Lower London Tertiaries, which he had recorded and described to a meeting of the Association in 1928 ; he did not at the time seek publication, and was only induced to publish it in connection with his last Field Meeting.

Gossling served on the Council of the Association from 1922 to 1926, and in 1932 was presented with the Foulerton Award. He will be remembered by many members of the Association for his kindly but retiring disposition, and by the members of the Weald Research Committee for his acute observation and meticulously accurate field work.

[A.J.B.]

Harry Philip Nurse, who died after a short illness on 11th May, 1945, at the early age of 42, joined the Association in 1930. He was born in Waltham Abbey, but while still a baby he moved with his family to Twickenham, where his father owned a nursery ; here he early developed an enthusiasm for field natural history. Leaving school at the age of 15, he obtained employment at an engineering firm and attended evening classes in commercial subjects. Although later he secured a post in a bank, he continued, in his spare time, to assist his father in his horticultural work. He studied geology, botany, and other natural science subjects as an evening student at the Chelsea Polytechnic, where he was an active and enthusiastic member of the Polytechnic Geological Field Club.

In his youth he was a keen collector of British lepidoptera and observer of birds ; later he extended his activities to field botany and ecology, becoming a member of the British Ecological Society in 1932.

Although of a quiet, retiring and somewhat serious disposition, his wide knowledge and experience in the field of natural history, combined with his readiness to help his less experienced friends, made him a delightful and popular companion on excursions. He typified, perhaps, that large and essential part of the Association's membership—the observant and reflective amateur with wide interests and a broad outlook.

[C.P.C.]

CATHERINE ALICE RAISIN, D.Sc., F.G.S., the daughter of a pannierman at the Inner Temple, was born in Camden New Town on 24th April, 1855, and died at Cheltenham on 12th July, 1945. She was a member of the Geologists' Association for sixty-seven years, and at her death was its most senior member. Of unusually strong physique, she retained her faculties to the end although in 1932 she was reported in *The Geological Society of America 1888-1930* (Fairchild, p. 110) to be " not now living."

Miss Raisin was educated at the North London Collegiate School and entered University College in 1873, later studying geology under J. Morris and T. G. Bonney and attending lectures by T. H. Huxley at the Royal School of Mines. She took her B.Sc. in 1884 and for some years acted as honorary research assistant to Professor Bonney at University College. In 1890 she succeeded Grenville A. J. Cole as Head of the Department of Geology at Bedford College for Women, a post she held for thirty years until retirement at the age limit. She was also Head of the Botany Department at Bedford College from 1891 to 1908. Teaching was her main life's work and among the many students who studied under her may be mentioned Dr. H. M. Muir-Wood, Dr. I. E. Knaggs, and Dr. Doris Reynolds.

Dr. Raisin's published papers, some in collaboration with Professor Bonney and numbering twenty-four in all, appeared between 1887 and 1905, most of them in the *Quarterly Journal of the Geological Society* and the *Geological Magazine* and one in the *Proceedings* of the Geologists' Association on " The formation of chert and its micro-structures in some Jurassic strata " (1903). Miss Raisin had a great admiration for Professor Bonney and much of her research work was carried out under his inspiration. She was an excellent microscopist, using the most up-to-date techniques of her time. She published the results of field and laboratory study of rocks from Devon, Caernarvon, Anglesey, the Ardennes and Switzerland, and the petrography of rock collections from Jersey (spilites), the Karakorum Himalayas, and many parts of Africa. Serpentines were an especial interest and her conclusions are given in her last paper (in collaboration with Professor Bonney) on " The microscopic structure of minerals forming serpentine and their relation to its history " (*Quart. Journ. Geol. Soc. 61*, 1905).

Miss Raisin was a charming woman, and a masterful. As befits a pioneer, she was also " a character." She ruled absolutely in her own sphere and dealt summarily with opposition. All unauthorised perambulation in the Geology Department at Bedford College was quickly stopped, the teaching given by her assistants was carefully scrutinised and in committee she was a doughty, and, to the weaker brethren, an intimidating fighter. She was extremely kind to her students and was affectionately known among them as " The Raisin " and (surreptitiously) " The Sultana." Ever solicitous for their welfare and good name she has been known in the field to immediately take her class out of a quarry upon the arrival of a male party from another college.

Living at a time when women were still excluded from official participation in many educational and geological fields, Miss Raisin entered each door as it was opened and in this respect she was the most noted pioneer among women geologists. She was the first woman to study geology at University College, the second woman to be awarded the London D.Sc. in geology (1898), the first woman to receive an award from the Geological Society of London (the Lyell Fund, 1893), one of the first women who became Fellows of the Geological Society of London when it tardily admitted women in 1919, the first woman—and to date the only one—to be Head of a University Geological Department. The name of Catherine Alice Raisin stands high amongst those women who soberly and untiringly furthered the cultural advance of their sex in the latter part of the nineteenth century. She passes full of years and honour.

[L.H.]

ANDREW TEMPLEMAN was born at Aberdour in Fifeshire on 22nd April, 1887. For some years he worked in a merchant's office and while there attended the Herriot Watt College, Edinburgh, for two or three years as an evening student. There he gained the Wemyss Prize for obtaining second place in the Honours course in geology. He also attended classes at the Herriot Watt and Agricultural Colleges, Edinburgh, in botany and zoology.

From September, 1914, to November, 1918, he was in the Royal Scots Greys going to France in March, 1917.

He joined the Geological Survey as an Assistant on 2nd February, 1920, and for some years was employed as fossil collector. After the compulsory notification of borings and shafts for minerals came into force by the Mining Industry Act of 1926, he was appointed bore-inspector for the Survey and was so engaged when he met his death at Seaton, near Workington on 16th December, 1945, by losing his footing on a vertical ladder in a 50ft. shaft and falling into an accumulation of carbon-dioxide. He leaves a widow and a brother, who is now in Canada.

Templeman had an extremely good knowledge of stratigraphy as well as of fossils and was a worthy disciple of William Smith, the " Father of English Geology," in whom he was keenly interested. Templeman's knowledge of field botany was extensive nd varied and he had a good working knowledge of the birds nd beasts of the countryside—in short he was a born naturalist.

He was well liked by all his colleagues and made numerous riends in his travels round the country as fossil collector, bore nspector and in his private capacity. He will be missed by all, or he was a loyal friend and an industrious and reliable worker, ver ready to help by placing his knowledge at the disposal of others, et withall a man of considerable reserve.

Templeman joined the Association in 1920, and attended many neetings. In the field, his genial personality, dry humour, and vide knowledge made him a valuable asset to any party he accompanied. When it was a question of identifying a plant or a bird, r an obscure fossil, it was nearly always Templeman to whom ppeal was made, and seldom, if ever, was he found wanting.

[T.E.]

MARK WILKS, who joined the Association in 1904, and died on 3th August, 1945, at his home at Headley Down, Hants, aged 83, as a London school teacher and geology was his absorbing nterest. His pupils, who he frequently took on geological outings, ffectionately nicknamed him "Fossils," and several of them later ook up geology with real enthusiasm.

Early in the century he attended a number of Field Meetings f the Association and at least once acted as Excursion Secretary. e also took part with Dr. F. W. Bennett in his investigation of harnwood Forest.

On retiring into Hampshire, he became interested in the Hawksy landslide and in the "Farnham Wey." With his wife, Dr. lizabeth Wilks, he devoted himself to the work of the Headley own Rural Preservation Society, of which he was hon. secretary.

[L.D.T.]

HE NORTHWARD MARCH OF PALAEOLITHIC MAN IN BRITAIN

An introduction to a study of the evidences of earliest human settlement in Scotland)

By A. D. LACAILLE, F.S.A.

[*Read 7th October*, 1944.]

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I. INTRODUCTION

COTLAND can show no record of human occupation comparable to that of England and France. The first settlers f whom we have any real knowledge arrived in early post-glacial mes. A long history, therefore, lies behind them. It includes at of Palaeolithic man's northward wanderings governed by e-movements during the Pleistocene epoch of the Quaternary a. This is often called the Ice Age because it was dominated y the most evident glaciation of all time.

The causes of the Quaternary Ice Age do not concern us, but nly its main phenomena. It suffices to recall that the glaciation as heralded during the preceding Pliocene by increasingly cold onditions. These were initiated in several powerful Arctic centres here ice gathered and whence it radiated. The main European cus of supply and dispersal lay in Fenno-Scandia over the northern altic region, and included the British Isles with their own areas accumulation and distribution. In central and south-western urope the high mountain ranges nourished glaciers which filled nd flowed down the valleys to overspread the low grounds.

The glaciation did not produce one vast and united mass of e, but it shrouded many regions. Though localised itself, its effects were world-wide. The Ice Age, however, was not one long period of stagnation, for several times immense ice-sheets advanced and retreated. Climatic changes attended these movements, and had a profound effect on living forms. Some knowledge of how Britain was affected is necessary for a proper understanding of man's northward march.

Not long before the advent of the ice, north-western Europe was subjected to land-movements that reacted upon Scotland. The shores of that country, from extending farther out than now, sank, so that at the beginning of the Quaternary the outlines of Scotland resembled those of the present day. Subsequent oscillations took place, and for long Britain was united to a European continent much larger than the present; and, until about the middle of the epoch, land connections existed between Europe and Africa.

The Quaternary Ice Age, as the barrier between the living things of the past and the present, was a critical phase in Scotland's history. As with its coming old forms of life vanished, so with its going a new succession was introduced. Notwithstanding the fact that organic remains show that the ice at least once loosened its grip and then reasserted itself, they demonstrate the presence of life in Scotland only when the Pleistocene was far advanced. One can speak with more assurance of the general climatic improvement which accompanied the hesitating withdrawal of the ice, and which permitted the flora to develop and the fauna to immigrate. This amelioration was followed by the settlement of man in Scotland.

From the moment the importance of man's relation to the Ice Age was first recognised, an understanding of Pleistocene events became desirable. No problem, however, has more exercised geologists and others than that of correlating European ice-movements. The amount written on this subject is enormous, and bewildering in the confusion of views put forward. Yet, in 1909 when the work of Penck and Brückner [1*] on the glaciation of the Alps appeared, it was thought order had at last been reached. These disciples of James Geikie determined that the Pleistocene consisted of four major glacial invasions, and named these, in order of age, after Alpine valleys where best represented, (I) Günz, (II) Mindel, (III) Riss and (IV) Würm. They believed that these advances of the ice, during which the snowline descended by about 1,200 to 1,300 metres, had been separated from one another by three retreats, each of which gave rise to a period of interglacial climate, the second, between Mindel and Riss, being the longest.

The last (Würm) extension of the ice was twofold, a short retreat (Laufen) intervening between its maxima. It was followed by the Achen recession which ushered in the withdrawal leading to the post-glacial period. The deglaciation was marked by halts and even readvances of the ice. Again using local names, Penck designated the principal interruptions (1) Bühl (now often called Würm III), (2) Gschnitz, and (3) Daun stadia. At these stages the snowline in the Alps stood respectively at 900, 600 and 300 metres lower than today.

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* For List of References, see p. 79.

The human Palaeolithic cultures and their associations have been fitted into Penck's and Brückner's scheme of glacial and interglacial periods. However, it has become increasingly clear that, although broad correlations are indeed possible, palaeontology and human stages of cultural development cannot be made to conform to rigid divisions, the more so that it is now recognised that all the glaciations admit of more than one maximum, and interglacial periods were interrupted by cold spells. Also, geographical and even chronological variations do not allow the Alpine system to be applied universally in Europe. For instance, the Alpine ice has left no evidence of having exerted such widespread influences as did the ice-sheets born of Scandinavian glaciers whose action was very like that of the British flows, but on a far grander scale.

Great expanses of Europe, including France and the south of England, though never invaded by the ice, did not escape its influence. They underwent climatic and corresponding floral and faunal changes more or less pronounced according to their proximity to the ice. Early man, too, was greatly affected by these fluctuations, and with them his industries varied. Of such ice-free but periglacial regions, the Thames Valley is classic ground. The deposits of its terraces and the steps between enshrine many memorials of the Pleistocene and provide standards for comparisons and correlations in Britain [2].

Although the earlier glacial onslaughts of which we have evidence in England came from across the North Sea assailing the east coast, yet it was the ice fed by the Scottish snow-fields which is known to have predominated later in the British Isles. The glaciers, which then formed in the Highlands and Southern Uplands, crept out on both sides of the Scottish Midland Valley and coalesced. The records of the vast ice-sheet so formed reveal complicated movements in different directions, flows on occasion being opposed by powerful currents from other sources, and as a result splitting into widely diverging streams. Being constantly reinforced, the ice so waxed that it overrode the loftiest hills, eventually mantling most of the British Isles and spreading into the western ocean, probably as far as the edge of the Atlantic shelf corresponding to the 100-fathom submarine contour. Records of any earlier ice-movements would assuredly be destroyed in much of the territory shrouded during the great glaciation which involved the greater part of the British Isles, and which is regarded as the equivalent of the first Würm advance of the Alpine glaciers. The Scottish ice was then confluent with that impelled from Scandinavia. Although this great extension of the north-western European ice-sheets may perhaps not have been coeval with the peak of the Würm I advance in the Alps, yet it seems to be the merging of local variations and to belong to the same phase of glacial intensity. Thenceforth, the long reign of the ice in Scotland was punctuated by retreats and renewed advances, but for untold centuries the higher and north-westerly parts of that country lay buried.

Doubtless the succeeding lesser Alpine movements were due to the same general ruling cause which led to the final deglaciation of north-western Europe. In many of the affected regions the process was much the same, though not necessarily contemporaneous everywhere. Thus, ice continued to be active in mountainous countries long after more open territories had begun to enjoy more genial conditions. The great Scandinavian uplands and Scottish Highlands are cases in point with much in common. But at this juncture we need only consider how Scotland and England contrasted. In Scotland glaciers and uncongenial conditions still lingered on, while in England a mixed fauna and human cultures were spreading under an improving climate.

II. THE BRITISH DRIFTS

Where the ice held sway in the British Isles, its movements altered the face of the land, and are registered in the deposits of the Old (or Older), New (Newer or Younger) and Youngest Drifts [3, 74-102 ; **4**, 28-32]. The accompanying map (Fig. 8) shows the regions involved.

The area of the Old Drift lies between the sinuous line denoting the southernmost front of the ice in Britain, reached at the peak of the second glaciation, and the limits of the New Drift. In Old Drift territory the memorials are preserved of ice-movements older than any positively recorded in the north of England, Wales, Scotland[1] and most of Ireland. All that may be said at this stage is that the term Old Drift involves at least two glaciations, the intermediate limit between its maximum and the New Drift being as yet undetermined.

The denuded appearance and topography of the Old Drift contrast strikingly with the relatively fresh and varied surface of the New Drift, traceable across the South of Ireland and Wales,

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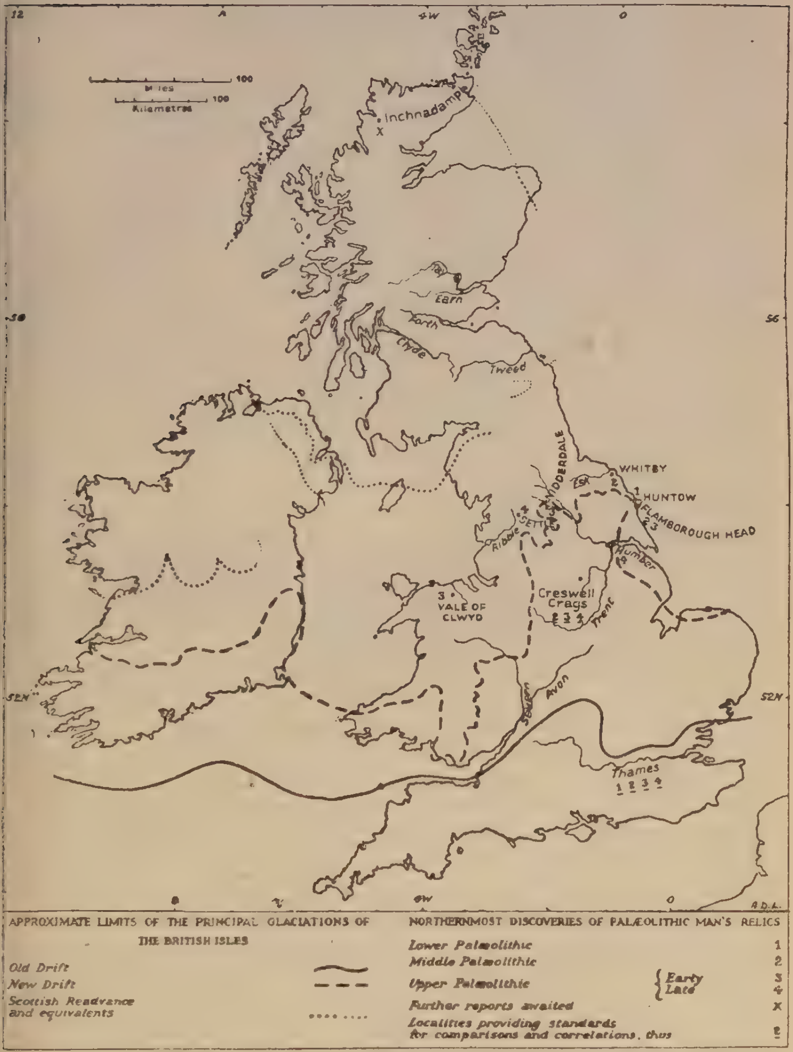
[1] Among the possible indicators of older glaciations are some shell-beds at Campbeltown [3, 368].

An abraded Acheulian ovate of riebeckite-microgranite of Ailsa Craig type was found in Taplow Terrace gravels at Dawley, Middlesex [6, 159-60]. From its facies and the conditions of its discovery there can be no doubt that the tool was fashioned long before the first recorded Scottish glaciation which is equated here with Würm I. The artifact, therefore, suggests that the raw material was carried southward by an ice-movement earlier than that known to have scattered fragments of the characteristic rock of Ailsa Craig.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SETTLE
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Humber
Creswell Crags
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Trent
3
VALE OF CLWYD
Avon
Severn
Thames
1 2 3 4
12
4
4W
0
56
56N
52N
8W
0
A.D.L.
APPROXIMATE LIMITS OF THE PRINCIPAL GLACIATIONS OF THE BRITISH ISLES
Old Drift
New Drift
Scottish Readvance and equivalents
NORTHERNMOST DISCOVERIES OF PALÆOLITHIC MAN'S RELICS
Lower Palæolithic 1
Middle Palæolithic 2
Upper Palæolithic Early 3
Late 4
Further reports awaited X
Localities providing standards for comparisons and correlations, thus 2

FIG. 8.—THE APPROXIMATE LIMITS OF THE PRINCIPAL GLACIATIONS OF THE BRITISH ISLES, AND THE NORTHERNMOST DISCOVERIES OF PALAEOLITHIC MAN'S RELICS.

along the Marches, in East Lancashire, over Yorkshire, along the east coast southward to the Wash and as far as Norfolk [**5**, 335 ff.]. The deposits of the New Drift mark the last great advance of the ice-sheets, and are late Pleistocene in age.

The Youngest (or lake-bearing) Drift speaks of the last struggles of the dwindling ice. It belongs essentially to the mountains of North Wales and Ireland, the Lake District, and the Scottish western Southern Uplands and Highlands.

The difficulties in interpreting the complex character of the drifts are increased by the fact that records of interglacial periods, which occur where deposition was dominant, are seldom disclosed. Moreover, the determining of advances is not easy, because successive forward steps of the ice may have ploughed through and obliterated deposits left in the trail of earlier movements. It is otherwise, of course, in the periglacial regions, where distinctions can be made. There, such layers as aggraded river terrace gravels are referable in the main to the later stages of interglacial periods, and solifluction deposits to glacial episodes.

To find drifts agreeing generally with the British Old and New series, one turns to the Baltic basin. There, too, the moraines, undrained hollows, and unsilted lakes, all products of the latest glacial activity, can be likened to features connected with the final stages of the Ice Age evidenced in our Youngest Drift. That these similarities exist is not altogether strange because the British glaciation and deglaciation were largely concomitant with the growth and decrease of the Fenno-Scandian ice. Hence, we look to the Baltic area rather than to the Alps for correlative data. The key, however, appears to lie in the English North Midlands where certain archaeological findings suggest agreement with the late Alpine scale.

Here we need only consider the chief events represented in the areas of the British drifts. To assess the implications of the various movements, it behoves us to examine some aspects of life during the Ice Age.

III. THE PLEISTOCENE FAUNA AND MAN

It is improbable that any Scottish Pliocene floral and faunal remains escaped obliteration by Pleistocene ice-movements. Yet, it may be supposed that pre-glacial life in Scotland was not unlike that farther south, because long before the Ice Age Scotland shared a genial climate with the rest of Britain and Europe.

As the preglacial epoch ran its course so the climate grew colder until it became arctic. It can be imagined, therefore, that there were great floral changes and faunal migrations as conditions developed to their climax. With the full brunt of glaciation, life, which had steadily decreased as the cold intensified, virtually disappeared from the areas swept by the ice. Naturally, the borderlands of these regions altered as did conditions therein when the ice retreated and advanced.

An ideal succession of floral belts, each having its characteristic fauna, between a warm region with luxuriant vegetation and a lifeless ice-field would be : forest ; open country ; grassy steppe broken occasionally by patches of bush ; and barren tundra. The passage from the Pliocene warmth in south-east England to the peak of glaciation is such a record, showing that ice-movements affected vegetation, and through it the fauna.

Of course, the sequence was reversed as the ice drew back. With subsequent advances and retreats the order was maintained, allowance being made for the fact that neither glacial intensity nor withdrawals were everywhere uniform or synchronous. Sets of animal remains, therefore, if numerous and varied enough, help to determine whether milder periods were due to fluctuations of the ice-front or to true interglacial stages.

During the Pleistocene some animals deserted Britain, others became extinct, and newcomers appeared. Their environment can be deduced in some cases from analogy with creatures still living.

Animal and plant remains found in deposits throw light on once prevailing surface conditions. Thus, we learn that different kinds of deer, horses and oxen figured prominently in the climatic scenes of the Pleistocene. Our imagination is stirred by the knowledge that a variety of large carnivores existed in Britain. This last group, however, is not particularly informative because the distribution of its species depended mainly on their wonted prey. The most remarkable Pleistocene animals were the great pachyderms. Of these, the hippopotamus did not persist so long in Britain as the elephant and rhinoceros, the species of both of which became adapted to a temperate climate and finally became able to withstand extreme cold.

The elephants are important chronological indicators. The warm southern type, *Elephas meridionalis* Nesti, characterised the Pliocene. It may later have been associated with another, *E. trogontherii* Pohlig, intermediate with it and the straight-tusked *E. antiquus* Falc., essentially an animal of interglacial periods. In the cold resisting and thick-haired mammoth, *E. primigenius* Blum., the form reached the height of its evolution.

The rhinoceros has not been so clearly defined, but the interglacial *Rhinoceros megarhinus* Christol and *R. hemitoechus* Falc. have been separated from the woolly form, *R. tichorhinus* Fischer, of severe climates.

In time the mammoth and woolly rhinoceros were joined by the reindeer. This companionship, which seems to have been formed relatively late in south Britain, ended in Scotland.

Man also adapted himself to the rhythm of the Pleistocene. The archaeological and allied evidence of the Thames Valley and other periglacial regions points to the movements of two Lower Palaeolithic human groups: one, southern manufacturers of core-tools, with warm interglacial periods; and the other, makers of flake-implements from the east, associated with severe climates. During overlaps these people mingled and their industries blended, but in general the alternations held good until cultural elements fused before the coming of Upper Palaeolithic man.

The relationship between the Pleistocene mammals and Palaeolithic man, on the one hand, and the drifts of Britain, on the other, is gradually becoming clearer. Of course, mammalian life was impossible within close reach of the ice. But as this melted back so animals and man advanced into the freed territory which they forsook for more congenial surroundings when the cold returned.

Man's northward wanderings in Britain with the Pleistocene animals can be traced by his industrial relics ranging from Lower to evolved Upper Palaeolithic, discovered in areas progressively made habitable by the withdrawal of the ice-sheets. So far, Palaeolithic man's trail cannot be certainly followed much beyond the North Midlands.

The succession of events in the Old Drift area, to which man and his animal companions adjusted themselves, agrees broadly with the Continental order [7]. This is not surprising, for England during the Pleistocene was but an extension of the northern French cultural province, very similar conditions obtaining in both regions.

IV. THE LOWER PALAEOLITHIC AGE

Man probably co-existed in south Britain with the last warm and temperate and cold faunas before the first glacial episode which is possibly registered in the Red and Weybourne Crag and the oldest drift of the Chilterns. The real beginnings of human occupation in Britain, however, lie in the genial period that followed, when Abbevillian users of hand-axes roamed where they could with a warm fauna having strong Pliocene affinities. Among these animals were the southern and straight-tusked elephants, the older types of rhinoceros, and the sabre-toothed tiger.

Gradually these conditions changed to cold as ice developed once more and advanced. This movement culminated in the farthest southerly extension of the ice in Britain. The hand-axe people and the warm fauna were forced back and replaced by Clactonian flake-implement makers and hardier animals. These Clactonians and their four-footed companions survived this glaciation, whose deposits form the North Sea Drift, until the climate so improved that industrially more developed hand-axe makers, the Acheulians, and a moderately warm fauna succeeded them. Artifacts and organic remains show to what extent these new immigrants spread in England.

That the ice drew back far during this second interglacial period, the longest of the Pleistocene, appears from discoveries of mammalian remains in the north of England. Among several sites in Yorkshire, the most northerly of all, the Victoria Cave, Settle, has yielded a bone of hippopotamus in derived and much rolled condition with the vestiges of a much later fauna, probably contemporary with the containing deposit [**8**, 97 ; **9**, 36]. A claim for the human origin of a bone discovered here with the animal remains was challenged [**10**, 466–7], but a surface-found hand-axe (Fig. 9, No. 1) from Huntow, Bridlington [**11**, 23] and a worked flake from Chester [**12**, 26] testify to man's movements beyond the Trent basin, including Lincolnshire [**13**, 91 ff.] and Warwickshire [**14**], probably during this mild period. Also, some stones from Nidderdale, Yorkshire, claimed to have been flaked by Lower Palaeolithic man are suggestive [**15**].

It is just conceivable that Lower Palaeolithic man could have wandered farther, but a quartzite flake from County Durham [**16**] advanced tentatively as evidence that he did so is not convincing. Less attention need be paid to other claims. Informed opinion rejects the scarred and fractured stones which have been collected in the north of England, Scotland and Ireland from coastal gravels, river-beds and boulder clays and put forward as Lower Palaeolithic implements [**17** ; **18**]. It sees nothing in them but the products of Nature's different workshops and the victims of her transporting agencies.

If any members of the fauna of the time strayed much farther north during this interglacial period, their bones would almost certainly have been destroyed by subsequent ice-movements. Should man have followed such animals there would be little possibility that his slighter bones could have escaped. Despite these considerations, there is always the remote chance that artifacts or organic remains referable to an early Lower Palaeolithic age may rest in exceptionally favourable situations such as an undiscovered cave.

The dearth of flint for making large tools has been raised as an objection to the occupation of the more northerly territory by Lower Palaeolithic man. But this argument cannot really stand, as countless palaeoliths fashioned in various hard rocks are found in many lands. Even in the area just considered, among the relatively few artifacts testifying to early man's push north of the Thames basin, the excess of tools worked in flint over quartzite and other rocks is not great. A weightier reason may have been that small populations were not impelled to leave reasonably congenial regions for others probably less able to support an abundant animal life. Besides, the way was beset with many natural difficulties. The mountainous country where ice gathered, and such formidable obstacles as great rivers must have discouraged migration.

When glacial conditions once more gripped the land many animals disappeared from Britain. But the career of Lower Palaeolithic man was not ended by this renewed onset of the ice, which is commemorated in the Middle Chalky Boulder Clay of East Anglia. For a time the hand-axe folk gave place to the precursors of Middle Palaeolithic manufacturers of flake-implements in the Clactonian tradition and in nascent Levalloisian style with Acheulian affinities. The temperate fauna, which had included late interglacial forms, yielded to cold-resisting animals, among which were early types of mammoth and woolly rhinoceros.

The deglaciation which followed was irregular. Since the ice withdrew but slowly, its proximity assuredly for long rendered the central Midlands inhospitable. However, the region was not continuously uninhabitable, for a few Levalloisian flake-tool manufacturers, like their forerunners, wandered into the Trent basin. With them went the mammoth and woolly rhinoceros. That such ill-equipped men ventured so far into the wastes beyond the bleak Thames Valley of the time is indeed remarkable, but then life was now adjusting itself to an era of refrigeration governed by the vast northern ice-fields.

A period of milder climate preceded the next glaciation, the evidences of which so abound in Scotland, the north of England, Wales and Ireland. In the earlier part of the period the hand-axes that again were included in man's equipment consisted of highly evolved Acheulian types. Later, kindred implements were fashioned locally in south central, south and south-east Britain in the even more developed Micoquian (final Acheulian) style.

V. THE MIDDLE PALAEOLITHIC AGE

(*a*) *The Derbyshire Caves*

Towards the end of this, the third, interglacial period, Lower Palaeolithic man disappeared. His Middle Palaeolithic successors came into their own and for a considerable time preserved many of the old industrial traditions. The fauna and man can be traced with certainty as far as north-east Derbyshire, south-east Yorkshire and perhaps North Wales, which suggests that little more territory was open in the north.

During this interglacial period the sea encroached upon the land, its transgression being registered by a raised beach. This platform occurs from Yorkshire, around the south coast of England, in Wales, to Westmorland, and is represented in the Isle of Man. Its equivalent is found along the coast of Northern France and in the Channel Islands. In Ireland it is a feature in County Down in the north-west, in the south and to County Mayo in the west.

The position of the zero-isobase, from north-east England across to the west of Ireland, and distribution of this beach south thereof preclude its being confused with later strand-lines, although it has to be distinguished from pre-glacial platforms at approximately similar levels. As the raised beach stands but 10 to 25 feet above present sea-level, and is only locally overlain by glacial deposits, the coastlines of Britain during this interglacial period would resemble those of the present day.

Our knowledge of the northward progress of the Pleistocene fauna and human industry from this interglacial period onward comes mainly from caves. Those excavated in the Creswell ravine, Derbyshire, afford a complete stratigraphical record carrying the story of man and beast from Middle Palaeolithic to early post-Palaeolithic times [**19** ; **20**]. The sequence revealed here corresponds to the Alpine order of Penck and Brückner, and provides the basis of our correlations (pp. 77–8, below).

The Pin Hole Cave, Creswell, first records the sojourns of Middle Palaeolithic hunters sparingly equipped with flake implements of evolved Clactonian facies (*cf.* Tayacian, early Mousterian)[1] and crude tools made in the Acheulian tradition. Among man's associates during the more genial phase of this interglacial period were horse, bison, giant deer and lion.

(*b*) *The Great Glaciation of Scotland*

Under the influence of the waxing northern ice interglacial conditions gave way, finally yielding to arctic rigours. In the south the glaciation was heralded by an increasingly severe climate, shown by floral vestiges and shells, bones of mammoth, woolly rhinoceros, reindeer, bison, horse and rodents, found in the peaty and marshy deposits of the Upper Flood Plain Terrace, Stage I (or the Ponder's End Stage), in the Thames Valley [**21** ; **22**, 2, 65–7]. Man is believed to be represented by a Late Levalloisian (" Mousterian ") flake-implement [**23**, 91].

The many great advances of the ice-sheets from different centres which marked this phase may not have attained their peak simultaneously. All, however, contributed to the considerable shrouding of the British Isles. To this stage belong the Upper Chalky Boulder Clay of East Anglia and the Yorkshire Lower Purple Drift.

The counterpart of the advances which then assailed England was the Great Scottish Glaciation, whose main current moved south-easterly. The heavily charged till or basal boulder clay of the Midland Valley, in places proved to be of great thickness, attests the tremendous devastation wrought by the Scottish ice.

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[1] These tools may be regional developments on the Clactonian and Levalloisian stock. It is unlikely that true (cave) Mousterian reached England as it is unrepresented in Northern France, where Levalloisian takes its place.

But, however powerful, this could not entirely overcome the pressure of the Scandinavian ice-sheets. In the Moray region the Highland ice was split into two flows, one towards the north and the other towards the south.

Abundant Scottish and Scandinavian erratics in English east coast drifts proclaim that the principal stream was in contact with the North Sea ice-sheets. Another flow formed the glutted Firth of Clyde glacier which coursed southward and united with the ice developed in Ireland. There the ravages of the concomitant glaciation are registered in the Indurated Boulder Clay.

Central and southern England, though spared direct invasion, fell under the influence of the advancing ice.

(*c*) *The Subsequent Retreat of the Ice*

Eventually the intense cold was interrupted by a general shrinking of the ice-sheets. During the early phase of the thaw users of more developed Middle Palaeolithic tools accompanied a cold fauna at Creswell. Artifacts found on the coast of south-east Yorkshire [**24**] have been assigned to congeners of these people, to whom is ascribed a flake-implement of flint (Fig. 9, No. 2) recovered from boulder clay in Eskdale near Whitby [**12**, 36-37 ; **11**, 22]. These discoveries represent the most northerly range of the Middle Palaeolithic folk.

Subsequent events recorded at Creswell were very similar to those prevailing on the Continent with which they may have synchronised. Thus, as the climate became milder, so Middle Palaeolithic man gave way to representatives of *Homo sapiens* in the Upper Palaeolithic stage of cultural development.

VI. THE UPPER PALAEOLITHIC AGE

(*a*) *Developments*

Although southern and eastern England now opened to continuous human occupation, these regions were nevertheless influenced by subsequent readvances of the ice. Scotland, however, as the principal centre of these later movements, had still a long glacial history which was intimately bound up with that of the English North Country, Wales and Ireland.

Upper Palaeolithic hunters followed migrating herds across the land-bridge from the Continent and small groups scattered over south Britain. In time bands in successive stages of Aurignacian culture reached north-east Derbyshire, the equipment of some of the last being reinforced with Proto-Solutrean forms. At Creswell the relics of the earliest arrivals have been discovered with the remains of reindeer, mammoth, woolly rhinoceros, Arctic fox and variable hare, an assemblage suggestive of severe conditions. Later there came the horse, bison, red deer and reindeer,

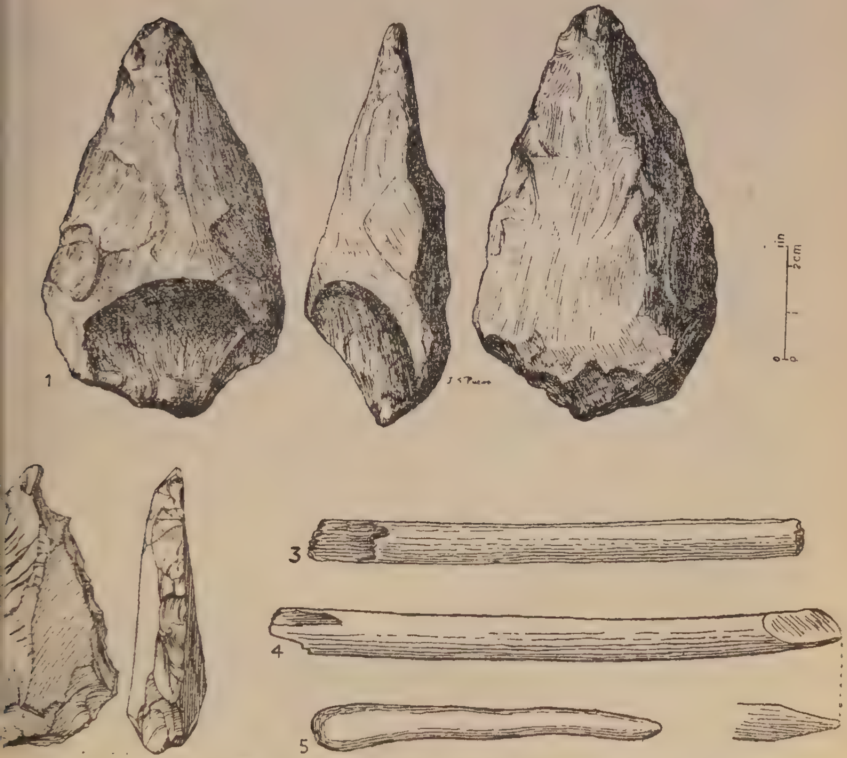

FIG. 9.—IMPLEMENTS AFFORDING THE MOST NORTHERLY EVIDENCES OF PALAEOLITHIC MAN IN BRITAIN.

Lower Palaeolithic, flint; Huntow, near Bridlington, Yorks. (After Elgee).
Middle Palaeolithic, flint; Eskdale, near Whitby, Yorks. (After R. A. Smith).
3-5. Upper Palaeolithic, reindeer antler; Settle, Yorks. (After Breuil).

an association indicating climatic variations and seasonal migrations. Cold conditions apparently predominated, but man was able to make casual stays at open sites in North Lincolnshire.

Changes of sea-level connected with advances and retreats of the ice may have intermittently cut the direct communication with the Continent [3, 295]. Hence, though reinforcing elements reached Britain, they infiltrated so slowly that by the time Magdalenian industries were flowering in France, after a return of cold followed by less uncongenial conditions, the English province had evolved an independent but basically Aurignacian culture.

The earlier cultural developments took place as the ice-sheets thinned and freed tracts of country as far north as the Scottish

Midland Valley. This liberation of territory was apparently little taken advantage of by man. Yet, relics proclaim that a few individuals ventured farther than the North Midlands. Thus, artifacts of Aurignacian and Proto-Solutrean facies, associated with animal bones, testify to man's fleeting sojourn in the Vale of Clwyd, North Wales [**25**, 104 ff.]. Early Upper Palaeolithic flint tools and surviving Late Middle Palaeolithic forms have been recovered with remains of mammoth, woolly rhinoceros and reindeer near Flamborough Head [**26**].

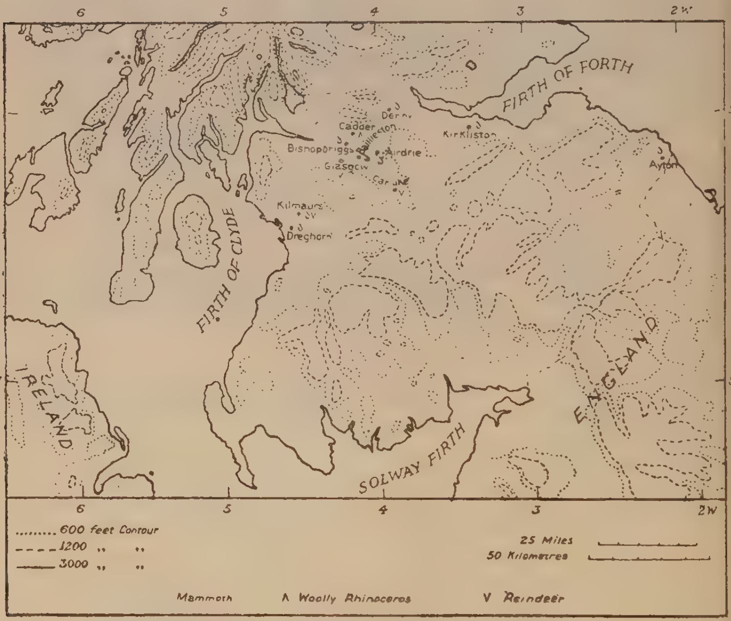

FIG. 10.—THE DISTRIBUTION IN SCOTLAND OF MAMMALIAN REMAINS ATTRIBUTABLE TO THE PERIOD OF CLIMATIC IMPROVEMENT BETWEEN THE GREAT GLACIATION AND THE NEW DRIFT.

A number of man's animal contemporaries far outstripped him in their wanderings. Of the hardier forms, which probably sought conditions more appropriate to them, the mammoth and reindeer reached Ireland by a partial land-bridge due to an isostatic uplift [**27**, 380], and both accompanied the woolly rhinoceros into Scotland. All three creatures may be referred to the fauna which was associated with late Middle Palaeolithic man, but which outlived him and spread during the stages of his successors' cultural development south of the Humber. The evidence points also to the migration northward of even less hardy forms during this period of climatic improvement. The remains of all these animals have been discovered over an area stretching from Ayrshire to Berwickshire (map, Fig. 10), but never beyond Forth [**28**, 190-2]. This fauna, the first known to have penetrated into Scotland since the Ice Age began, is referable in archaeological chronology to Upper Palaeolithic times.

(*b*) *Scottish Deposits of the Retreat Period*

The deposits formed in Scotland when the great ice-sheets melted back were mainly sands and gravels, sometimes with seams of clay and peat. The two last have often proved informative in their organic contents, the others seldom so. All deposits which cap those laid down by the great glaciation are significant. But, of course, the most interesting are the layers between the old and later boulder clays.

Most sections owe their exposure to river-cuts, and a number to the chance of commercial and engineering excavations. Last century many of these sections attracted geologists, including the brothers Geikie, who described several examples in Central Scotland. The valleys of Tweed and Clyde and of their tributaries provide innumerable cases. Some sections reveal aggraded fluviatile deposits comparable to those of England, but on a small scale. Bores have also disclosed pre-glacial river channels charged with stratified beds resting upon the basal till and overlain with the boulder clay of the succeeding advance of the ice.

Besides an isolated record of mammoth from Dreghorn, Ayrshire [**28**, 192], tusks of this animal and a skull and antlers of reindeer were obtained at Woodhill Quarry, Kilmaurs, in the same county [**29** ; **30** ; **31**, 325-30]. They were associated with seeds of *Potamogeton perfoliatum* Linn., *Ranunculus aquatilis* Linn. and *Hippuris sp.* and the beetle *Notiophilus aquaticus* Linn. in an estuarine or freshwater bed underlying a marine deposit containing foraminifera, ostracods and shells of *Pecten islandicus* Müller, *Tellina calcarea* Chemn. and *Leda oblonga* Sowerby (? *Yoldia arctica* Müller). This points to the transgression of a cold sea prior to the readvance of the ice responsible for the thick capping of boulder clays. The whole overlay a thin clay stratum, presumably an old land surface, itself resting on the bedrock (Fig. 11).

Reindeer bones and antlers recently reported from the Queen's Park District, Glasgow, have been ascribed to the interval of climatic improvement attending this retreat of the ice [**32**]. These remains were recovered from a stream gravel underneath boulder clay, which in turn was overlain with later arctic marine deposits.

Peat in a contorted layer between two boulder clays at Chapelhall, near Airdrie, a locality whence mammoth remains have come [**28**, 192], yielded insects, mosses, twigs and branches [**33**, 99], including those of dwarf birch [**34**].

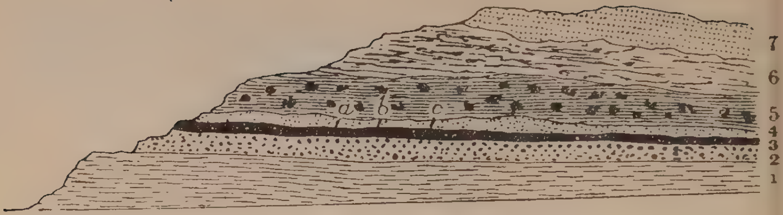

FIG. 11.—SECTION IN QUARRY AT KILMAURS, AYRSHIRE (After Bryce).

1. Carboniferous Sandstone.
2. Hard gravel and clay.
3. Fine dark blue clay, a freshwater deposit containing remains of Mammoth at *a* and *b* and of Reindeer at *c*, plants and beetle.
4. Coarse sand, a marine deposit containing shells, foraminifera and ostracods indicating cold conditions.
5. Reddish-brown boulder clay } Attributable to the New Drift glaciation.
6. Upper Drifts. }
7. Surface soil.

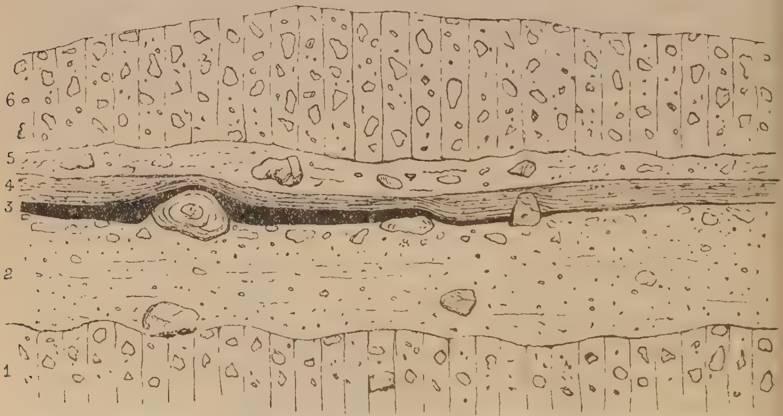

FIG. 12.—SECTION IN HAILES QUARRY NEAR EDINBURGH (After J. Geikie).

1. Lower boulder clay, attributable to the great Scottish glaciation.
2. Coarse earthy and gritty sand, with boulders most numerous at and near its upper surface.
3. Peat containing fragments of trees, apparently birch, with wing cases of beetles.
4. Blue sandy clay locally intercalated with peat or sand and silt abundantly charged with plant remains.
5. Coarse sandy clay containing angular and sub-angular stones and boulders.
6. Upper boulder clay, attributable to the New Drift glaciation.

Of the fossiliferous sediments farther east in Scotland, and referable to this period of deglaciation, two noted at Hailes, Midlothian [8, 256-61] are typical. One section (Fig. 12) showed a peat seam between two boulder clays. This peat contained remains of a decidedly temperate flora, but none of animals, though their presence was suggested by vestiges of *Geotrupes stercorarius* Linn., a dung-inhabitating beetle (scarabeid).

Equally instructive discoveries have been reported from the suburbs of Edinburgh. At Redhall Quarry, peat with associated deposits of sand and gravel between two boulder clays, contained the remains of beetles, hazel nuts, oak, alder, Scots fir, and of no less than fifty flowering plants, some no longer native to Britain [35, 181-2]. A sandy layer underlain and overlain by boulder clay at Craiglockhart Hill yielded tree-roots and other vegetable remains [36, 245].

Traces of plants and animals which lived between the great Scottish glaciation and its successor have sometimes, though rarely, been recovered from boulder clay and other glacial deposits in central Scotland. In their derived state the organic remains are invariably much injured and fragmentary. An example from the boulder clay is provided by an ice-scored piece of reindeer antler found at Raesgill, near Carluke, Lanarkshire [37, 5]. Glacial lake-gravels at Cadder, Dunbartonshire, have afforded the only bone of woolly rhinoceros known from Scotland [38, 395]. A morainic deposit at Headswood, near Denny, Stirlingshire, has recently yielded a molar tooth of the mammoth [39] which represents the most northerly record of this animal in the British Isles.

It cannot be doubted that mammals could have lived farther north at this time, for the extensive deglaciation in the north-east of Scotland referred to this period [40, 49] allowed a temperate flora to grow in that region. At the Burn of Benholm, Kincardineshire [41], this is shown by the pollen-analysis of marshy peat between the grey basal boulder clay and the red boulder clay of the Strathmore Glaciation (New Drift). Alder and oak occur throughout, with pine and birch predominating in the lower part, and elm and hazel in the upper. That the ice had probably retired far back into the Highlands is indicated also by the presence of derived peat in Aberdeenshire moraines of the subsequent Strathmore Glaciation [40, 18].

The scanty faunal remains and the more ample contemporaneous floral documents demonstrate that during this period of retreat a cooler climate prevailed in western Scotland than in the east and north-east. From this the proximity of lingering ice in the west is inferred. Evidence from Northern Ireland shows that like conditions obtained there [42]. In these regions, therefore, the climate would be that of an interstadial rather than an interglacial phase.

That the Pleistocene animals were prevented from straying farther north can be explained by the great water-barrier formed by the junction of the Forth and Clyde estuaries [28, 192]. Besides the sites in central Scotland which attest the reality of the contemporary marine transgression, raised beaches and other deposits south of the Cheviots show that it affected other parts of Britain. The plants and animals represented in beds associated with the submergence in the more southerly regions point to temperate conditions approaching those of an interglacial.

Although man at this time could probably have trailed the animals farther north in Britain, there is no evidence of his having done so. Moreover, he seems not to have migrated to Ireland, the northern part of which was then ice-free and rich in excellent flint for implement manufacture. Though he would hardly have found any appreciable quantity of this rock in those parts of Scotland which were open, yet other and fairly tractable materials would have been available to him. That man should not have pushed beyond known sites can be accounted for in several ways. The likeliest reason is that the chase of a few straggling animals would have offered the outposts of a tiny food-collecting population little inducement to leave fairly stocked regions. Despite these considerations, the possibility remains that man in a stage of *Late* Levalloisian (" Mousterian ") or Aurignacian culture may have reached Ireland and some areas in central and southern Scotland. If his skeletal or industrial relics indeed exist, they await discovery as (*a*) comparatively unaltered ingredients in beds formed during the retreat stage that followed the great glaciation, or (*b*) as derived and abraded constituents of later deposits.

(*c*) *The New Drift Glaciation*

Returning cold caused the less resistant members of the fauna to disappear from the outlying freed regions. Even the arctic forms which replaced them vanished in their turn as the glaciation progressed. The great pachyderms died out in their last British feeding-grounds, which were overwhelmed by the readvance of the ice-sheets nurtured in the Highlands and other centres. These movements were highly intricate and made up the complex of the New Drift Glaciation.

This glaciation of the British Isles was not so extensive as its predecessor (map, Fig. 8). But it enveloped the whole of Scotland, the north of England, and most of Wales and Ireland, the ice at its maximum stretching into the Atlantic Ocean. Only the loftiest hilltops and some high masses remained uncovered within all this area.

From the principal gathering-grounds in the Scottish Highlands the ice spread fanwise. The dominant constituent, the great Strathmore Ice-Sheet, invaded the Midland Valley and coalesced in central Scotland with ice impelled from the Southern Uplands. Ice-sheets once more bore across the North Sea, but in eastern and northern Scotland the native ice was powerful enough to fend off the assailing streams. Nevertheless, under the pressure offshore the trend of the Scottish flows was changed from south to north. The deflected currents involved Caithness and combined with the Scandinavian ice in oversweeping the Orkneys and Shetlands. Farther south, however, the North Sea ice exerted even greater influence. Along the seaboard it was in contact with Southern Uplands ice-streams moving over the Cheviots in a south-easterly direction. This is attested by Scottish and Scandinavian erratics in English east coast deposits. Among these beds are the Hessle-Hunstanton and associated boulder clays, which also proclaim that the onslaught of the northern ice stripped the coast from north of the Humber to the Wash and was brought up against the Cromer Ridge in Norfolk. The counterpart of the Scottish glaciation in the English North Country comprised advances of the ice east and west of the Pennines. The Cleveland Hills, however, stood out unglaciated in a region where great ice-lakes had been formed by the combined action of the Hessle and Scandinavian ice which dammed the Humber and the Vale of York.

Although not so vigorous as before, the Firth of Clyde glacier, being constantly reinforced, succeeded in overriding the shores of Donegal, Antrim and Down. It united with the ice which radiated from the Irish centre, but which spared a considerable expanse in the south. This is indicated by the distribution of the southern Irish End-Moraine. Ice urged from Scotland and Ireland filled the basin of the Irish Sea and occupied North Wales. Active glaciers in the rest of this last-named area contributed by their coalescence to its almost complete glaciation.

Layers containing floral and faunal remains of the retreat period preceding the New Drift have been found outside Scotland in areas vacated by the ice of the great glaciation. These beds, too, are capped by glacial deposits of the succeeding advance. In what concerns a survey of man's northward march, the most significant stratigraphical evidence is that showing the relationship of the New Drift glaciation to Upper Palaeolithic cultural relics. It is crucial for dating and purposes of correlation.

The New Drift closed the mouths of the caves in the Vale of Clwyd, burying the Aurignacian and Proto-Solutrean products mentioned in a foregoing paragraph (p. 70). Hessle boulder clay, referable to this glaciation, covered the sediments which yielded Late Levalloisian and Aurignacian implements near Flamborough Head [**26**, 374-80 ; **24**, 226 ; **43**, 267]. Presumably the boulder clay in Eskdale credited with a flint tool (p. 68) is of similar origin [**12**, 36-37]. Implements of Upper Palaeolithic type have been recovered also from glacial deposits attributed to the New Drift, at sites along the Humber [**44**, 130-2], Kirmington, Lincolnshire [**43**, 262-72 ; **45**], and South Hunstanton, Norfolk [**46**, 366-8].

Just on the outer fringe of the New Drift, outwash material from the end-moraine was deposited on the Aurignacian implements reported from Nidderdale, Yorkshire [**47**]. Some Upper Palaeolithic sites outside the immediate scope of the New Drift lay sufficiently near ice-swept territory to be sensibly affected.

Among them the open-air advanced Aurignacian stations in North Lincolnshire were burdened with solifluction masses assignable to this glaciation [13, 110]. By its action the Upper Palaeolithic layers in the Pin Hole Cave, Creswell, were sealed and the place rendered uninhabitable.

Bitterly cold and wet as was the Creswell Crags region at the peak of the New Drift glaciation, and boasting only a scanty arctic fauna, it was not altogether deserted by man. A neighbouring rock-shelter, Mother Grundy's Parlour, which had seasonally housed a similar succession of Upper Palaeolithic visitants, continued to serve as a refuge.

(*d*) *The Retreat of the New Drift Ice*

When the New Drift ice withdrew some exponents of the latest Upper Palaeolithic culture roved in the vacated territory. But only the Victoria Cave, Settle, on the west side of the Pennines water-parting, speaks positively of man beyond the North Midlands during this period of deglaciation. The memorials of his passage, and those surely proclaiming Palaeolithic man's farthest progress north, consist of a few implements of Magdalenian type in reindeer antler (Fig. 9, Nos. 3-5).[1]

During this stage the ice melted in the Atlantic Ocean and receded from its front in Wales, the Irish Sea and Ireland ; and the Scandinavian ice-sheets drew back from the British east coast. With these movements the general deglaciation began, but the process proved long and irregular, for pauses and readvances interrupted the retreat. On our mainland the withdrawal of the New Drift ice freed the north of England, the lower Tweed Valley and even tracts in the north and north-east of Scotland.

Since the general trend of the retreat in Britain was towards the mountains in the north and west, the low grounds sloping towards the North Sea were bared. Therefore, if man advanced northward and penetrated into Scotland at this time, his relics may lie in some sheltered straths and valleys in the North Sea basin, and his trail should be sought in the flatter north-eastern English and eastern Scottish country rather than in the hilly west. The possibility that such traces exist has been suggested by flakes found near Comrie, Perthshire [48], in what may be an interstadial deposit referable to this period [49, 48]. However, the specimens from this locality, now preserved in the County Museum, Perth, are not acceptable as artifacts.

For Creswell and a great part of Britain a new age dawned with the oscillation which caused the New Drift to recede towards the Scottish Midland Valley. Man's progress in England thenceforward belongs to another chapter. Suffice it to say meantime that the

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[1] J. W. Jackson now reports a barbed point of antler from the Victoria Cave. *Antiq. Journ.*, XXV (1945), 147-8.

Pin Hole Cave and Mother Grundy's Parlour, lying *outside* the end-moraine of the New Drift, are the type-stations of the English Upper Palaeolithic. On the score of its characteristic facies this has been named *Creswellian* [**25,** 194]. It developed contemporaneously with the Magdalenian of France. To the Creswellian and to elements from the overlying archaeological levels at Mother Grundy's Parlour most of the earliest unambiguous expressions of human culture in Scotland trace their ancestry [**50**]. They are the products of Mesolithic industries at shore occupation-sites.

VII. CORRELATIONS

The sequence from Middle to Upper Palaeolithic at Creswell Crags provides a datum for the tentative correlation of British and Continental late Pleistocene events.

(a) In Western Europe the late Palaeolithic cultures developed in like conditions with similar faunas. The place of the Aurignacian is crucial because the contemporaneity of the culture on the Continent and in England is accepted. On the Continent Aurignacian culture gradually superseded the Mousterian and Late Levalloisian, and throve during the Laufen retreat or "Aurignacian oscillation" [**5,** 351] between the first and second Würm maxima in the Alps. In England it partly co-existed with and replaced the late Middle Palaeolithic during the retreat of the ice-sheets which had been responsible for the Scottish basal till, the Yorkshire Lower Purple Drift, and the Upper Chalky Boulder Clay. It is reasonable, therefore, to correlate (*a*) the first positively recorded glaciation of Scotland and concomitant advances of the ice with Würm I, and (*b*) the succeeding Continental and British spell of climatic improvement.

Before the second Würm onset Aurignacian culture gave place in some parts of Europe to Proto-Solutrean. This heralded the full Solutrean that flowered locally on the Continent during Würm II. The Proto-Solutrean made a slight impression upon the English Upper Palaeolithic before the peak of the New Drift.

The Continental Magdalenian and the English Creswellian grew contemporaneously [**19,** 168–74], the former during the Achen recession after Würm II and the latter as the New Drift ice retreated.

(b) A consideration of the bonds between British and Fenno-Scandian ice-movements upholds the foregoing correlations. The westerly drive of the ice-sheets across the North Sea came into contact with streams of the great Scottish glaciation. It was concomitant with the Warthe glaciation, whose front is denoted by the Fläming moraines in Germany and Denmark. It is commonly held that the Warthe glaciation is the equivalent of Würm I.

The submergence of the fringes of Britain during the retreat preceding the New Drift corresponds to the transgression of the Eem Sea during the melting of the North Sea and Warthe ice-sheets. Floral and faunal remains, Late Levalloisian and Aurignacian implements from the March-Nar deposits associated with the marine invasion indicate that the southern parts of Britain and the adjacent Continent at this time enjoyed similar temperate conditions [**51**, 222–4 ; **52** ; **53**, 216].

The subsequent Weichsel glaciation of the Baltic area, regarded as the equivalent of Würm II, had a counterpart in the recrudescence of the North Sea ice-sheets which influenced New Drift flows along the British east coast. The post-Aurignacian age of the New Drift is manifest, since deposits referable to this glaciation overlie Aurignacian and Proto-Solutrean relics.

(c) The long process of deglaciation opened in the British Isles with the retreat of the New Drift ice and the drawing back of the ice-sheets from our east coast. Around the Baltic it began with the waning of the Weichsel ice which, receding from its edge marked by the Brandenburg End-Moraine, bared most of Northern Germany. Man entered the freed Elbe basin, where he eventually developed the typical Hamburg culture [**54**]. His earlier migrations would parallel that evidenced by the late Upper Palaeolithic relics at Settle. Because this phase also witnessed the liberation of Denmark, it is called the Daniglacial period. It is equated with the Achen recession of the Alpine glaciers.

(d) If these correlations are valid, then the earlier major episodes bearing on Palaeolithic man in Britain fall into place as shown in the accompanying table [**55**, 159–60 ; **56** ; **57**, 406–10]. This broad scheme includes the subsequent readvance of the Scottish ice, which corresponds to the third Würm (Bühl) phase of glacial activity in the Alps. The Würm glaciation of Alpine chronology is therefore the background of prehistoric Scotland.

VIII. THE ANTIQUITY OF MAN IN SCOTLAND

From the foregoing it appears that the possibility of Palaeolithic man's having reached Scotland during an interglacial period or spell of climatic improvement may not be ruled out. So far, nothing proves that he did so.

The reader may have in mind the possibilities of Scottish caves as Palaeolithic stations. He will remember the suggestion that the charcoal, horn implement and marks on reindeer antlers from the lower strata of a cave at Inchnadamph, Sutherland, are attributable to late Palaeolithic man [**58**, 171]. These relics have been considered to ante-date the last extension of the Highland ice, namely the Valley District or Moraine Glaciation, a much later event than any mentioned in the foregoing. In that case the retreat of the ice in the penultimate stage of deglaciation would have been more extensive and the conditions more congenial than was formerly thought. On the other hand, the animal bones may represent an arctic fauna which survived into early post-glacial times. If so, they would be Mesolithic, or even Neolithic in age as was believed of similar remains from an adjacent cave [59, 343]. Whatever the interpretation, traces of man's progress towards Sutherland should be sought and assigned to their true horizon. Because of the archaeological, geological and palaeontological implications of the Inchnadamph site a further report is eagerly awaited.

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THE TERRACES OF BOURNEMOUTH, HANTS

By J. F. N. GREEN

[*Read 6th July, 1945.*]

INTRODUCTION

NUMEROUS researches, both in this country and the continent, converge to the conclusion that the terraces of our southern rivers are due to eustatic movements of the sea. In 1936 the writer tried to summarise our knowledge of these movements, but it could not be said at that time that the terraces of any district were known with any degree of precision.

Bournemouth is built on and surrounded by a series of well-preserved terraces, little dissected by minor tributaries. For some years the writer has been mapping much of this area on the six-inch scale. As the work progressed, it became clear that over a large district every part of the ground, including the valleys of the smallest rivulets, fell into a scheme of ‘ treads and rises ’ or ‘ flats and bluffs,’ so that the geomorphological position of almost every point could be stated. In fact over the area of 24 square miles covered by the six-inch sheets Hampshire 85 East and 86 West, it is probable that there need be no doubt about more than a score of acres above 20 feet O.D.

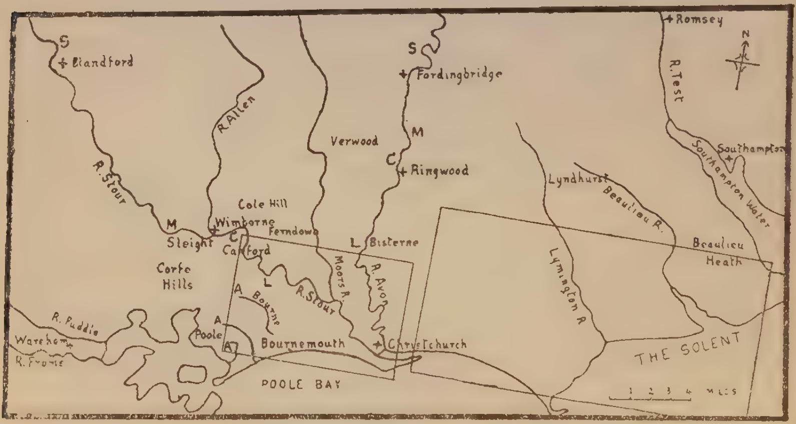

FIG. 13.—INDEX MAP.

A, Beheaded valleys ; S, Head of Staverton rejuvenation ; M, Head of Upper Buried Channel ; C, Head of Christchurch rejuvenation ; L, Head of post-Christchurch rejuvenation.

It is therefore possible to write with some confidence of the succession of morphological terraces in the district ; and it is these alone which have been mapped. References to their heights relate therefore to the surface levels, determined as far as possible on the flats. In consequence, the perimeters are usually within lines bounding terrace-gravels, which include part or all of the bluffs. No attempt is made to date these terraces or terrace-gravels, archaeologically or glacially.

The country to be described is divided geologically by the Avon valley into two sections differing in morphological behaviour. In the west, the Bagshot and Bracklesham Beds are sands with only subordinate clays and pebble-beds ; in the east, the solid basis consists mainly of the clays and loams of the Barton Clay and Headon Beds, though between them the Barton Sands form some important spreads. All the terraces described in detail are shaped on these formations, usually with six to ten feet of gravel on those which are not deltaic. The most important are those of the Avon, Stour and Solent rivers. The Moors River, a tributary of the Stour, drains much of the area between the Stour and the Avon. The little Bourne, from which Bournemouth takes its name, plays a somewhat similar part between the Stour and the Solent River. Between the Avon and Southampton Water, terraces of the Lymington and Beaulieu rivers, once tributaries of the Solent, have not been studied.

The foundation of our knowledge of the terraces was laid by Clement Reid in the Survey Memoir on the geology of Ringwood [**1***]. His six-inch maps, preserved in the library of the Geological Survey, have never been surpassed for accuracy and detail ; but it has to be borne in mind that they are geological, not geomorphological maps, and that where gravels of two or more terraces are continuous, they were mapped together. Much additional information has been given by Osborne White in the second edition of the Bournemouth Memoir [**2**], which embodied Reid's work, and in a series of papers by Bury, many of which are cited in the following pages.

The terraces present, excluding any below 20 feet O.D., are as follows :—

A. *Marine.*

The 300-foot, 100-metre or Sicilian Terrace.

B. *Terraces connected with the Solent river.*

The Upper Ambersham Terrace. This, with the next, constitute the Eolithic Terrace of Reid.

The Ambersham or 200-foot Terrace.

The Sleight Terrace.

The Boyn Hill Terrace. In the Stour this is the Higher Merley Terrace of White [3, p. 56]. The Palaeolithic Terrace of Reid includes this and the next terrace.

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* For List of References see p. 99.

The Upper Taplow or Iver Terrace. In the Stour this is the Lamb's Green Terrace of White.

The First Lower Taplow Terrace. In the Avon this is the Bransgore Terrace of White.

C. *Terraces connected with the present drainage to Poole Bay.*

The Second Lower Taplow Terrace.

The Staverton Terrace.

The Upper Buried Channel flood-plain. This does not become an elevated terrace.

The Muscliff Terrace, a delta.

The Christchurch Terrace.

The series of terraces below the Taplow corresponds to a series of graded reaches in the lower courses of the rivers, previously lumped together by the writer as the 'plunging profile' [**1**, p. lxxvi).

THE SICILIAN TERRACE

In 1902 Reid described a 'Highest Terrace' with upper limit about 350 feet O.D. [**1**, p. 39]. In 1923 Bury [**5**, p. 28] pointed to the evidence of marine origin afforded by the contours and compared the platform with the continental 100-metre beach.

The portions nearest Bournemouth are, on the east, Burley Hill, continued northward by Vereley Hill (312 feet O.D.), outliers of a wide expanse east of Ringwood; on the west, a chain of small fragments at the highest part of the Corfe Hills. The largest, on which stands a reservoir, is at 285 feet O.D. Near it are many exposures of gravel, the stones of which are mostly more rounded than in the river-gravels below; the gravel approaches a shingle and is probably disturbed and rearranged beach material.

This marine plain must once have extended over the area discussed in this paper, and may be regarded as the face of the block from which the scenery has been sculptured.

THE UPPER AMBERSHAM TERRACE

Until recently this was confused by the writer with the next, from which, near the coast, it is separated by 20-25 feet only. It appears to have been a short episode, so that it diverges from the main Ambersham Terrace on proceeding upstream. It does not occur in the area of the map (Pl. 5), but its approximate limits east of the Avon are shown in Fig. 14. White noted its presence here at Dur Hill Down, doubtfully correlating it with Reid's Highest Terrace [**3**, p. 49].

The terrace is well developed on the Corfe Hills. From the Sicilian Terrace a bluff with a slope of one in 30 falls to a flat at 266ft. O.D., which can be traced towards the Stour to 250 feet O.D. It is similarly found, but much dissected, against the Sicilian of Burley Hill. The expanse on Dur Hill Down is mostly from 250 to 240 feet O.D.

At present the only other river where the Upper Ambersham has been definitely separated is the Devonshire Dart.

THE AMBERSHAM TERRACE

An account has already been given of the history of our knowledge of this terrace [**3**], to which may be added that it is probably the Winter Hill Terrace of Miss Saner and Dr. Wooldridge [**4**] and that, if this is so, that name has priority.

Fragments of the terrace occur south-east of Sleight, but it is better preserved at 240 feet east of the Corfe Hills, whence it is easily followed for three miles across Canford Heath, the eastern part being shown on map (Pl. 5) from 214 to 200 feet O.D. Nothing more is seen of it eastward belonging to the Stour or Solent, but after nine miles it occupies much of the angle between the Avon and Solent, especially about Plain Heath. It continues to a point a mile north of Sway (Fig. 14). The lower edge east of the Avon lies consistently about 190 feet O.D.

It appears that over an area round Bournemouth, perhaps 30 by 20 miles, the country was reduced in later Ambersham time to a ' panplain ' by concurrent rivers. The plain only varied in height about 80 feet and the slope was rarely as much as one in 150.

THE SLEIGHT TERRACE

This terrace was first defined at Sleight, south-west of Wimborne, by Bury in 1923 [**5**, p. 22]. In 1933 [**6**, p. 331] he correlated terraces at Mount Talbot and St. Catherine's Hill with it. As early as 1889 Westwood had distinguished it for several miles as a ' 150-foot terrace ' from those above and below it near Fordingbridge [**7**]. His work seems not to have been accepted by Reid, who, however, wrote of a gravel spread, east of Fordingbridge, " It seems to form a connecting link between the Eolithic and Palaeolithic terraces, or perhaps should be considered an independent terrace " [**1**, p. 41]. This spread is part of the Sleight Terrace.

The terrace was not noted by the Weald Research Committee in the river Mole and no sign of it appears on the published profile [**8**, plate 2]. The writer has, however, been allowed to examine a more exact profile of the river Test, prepared by Miss K. Boswell, who has measured the ordinary water-level to tenths of a foot at intervals averaging one-sixth of a mile. This profile shows the Sleight nicks, and also indicates that the Sleight-Boyn Hill nick would have been obscured if the intervals had averaged a mile, as in the case of the Mole. There can be little doubt that an equally detailed profile of the Mole would show a corresponding nick. The terrace has been identified in the Axe, Otter, Exe and Dart, though not so well developed as at Bournemouth.

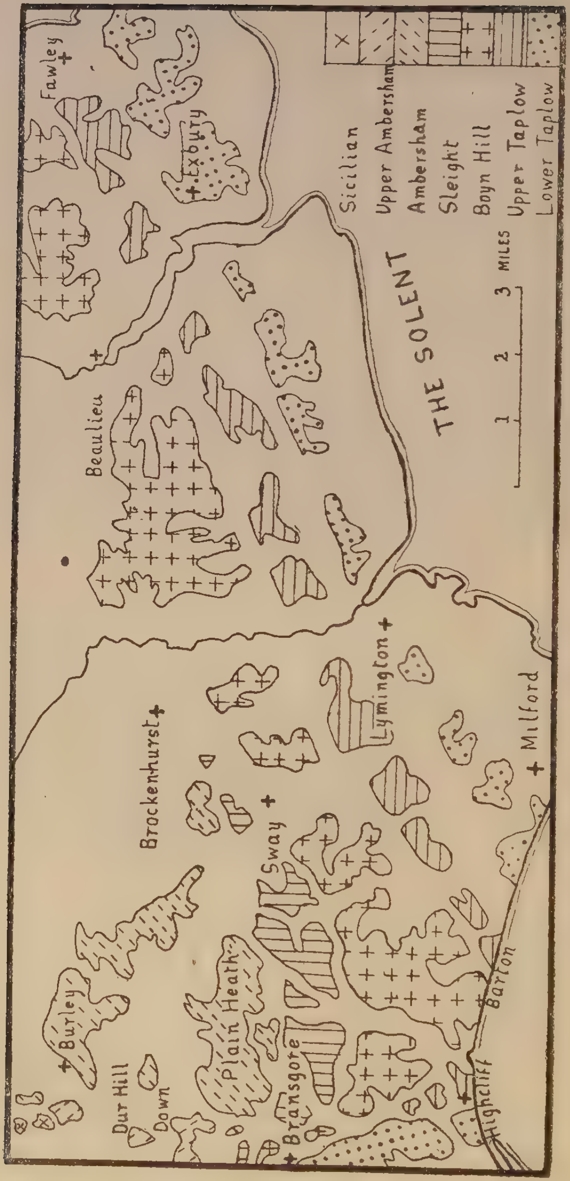

FIG. 14.—TERRACES BETWEEN THE AVON AND SOUTHAMPTON WATER.

North of Sleight the lower edge of the terrace is about 205 feet O.D. Much of it is preserved south of Canford. The largest relic near Bournemouth is at Talbot Village, where a continuous flat, six miles long and usually about two miles wide, descends gently from 190 to 165 feet O.D. (Pl. 5). Two fragments are preserved on the summit of St. Catherine's Hill in the Stour-Avon angle, at levels of 182 and 163 feet O.D.

East of the Avon the Sleight terrace of the Solent river is nearly continuous to Sway. The lower edge is usually at about 165 feet O.D.

THE BOYN HILL TERRACE

This is the most evident of the Bournemouth terraces. It is wide-spread at 150 feet at Pamphill, west of Wimborne, but otherwise is not well seen along the north side of the Stour. On the south side, at Merley House, opposite Wimborne, it slopes from 160 to 145 feet and thence runs for five miles to Winton, where it amalgamates with the Boyn Hill Terrace of the Solent to form the plain on which most of Bournemouth is built. This is very level, varying only from 150 feet at its western edge to just below 120 feet. It tops the cliffs for three miles east of Bournemouth pier and in historic times extended some distance farther south.

The summit of Hengistbury Head, once part of an interfluve between the Stour and Avon, is flat at 116 feet O.D. The Boyn Hill terrace of the Solent is well preserved east of the Avon from Hinton to a large extension, much like the Bournemouth plain, overlooking Hythe (Fig. 14).

The difference of the sea-levels, to which the Boyn Hill and Sleight terraces were graded, was between 40 and 45 feet. The separating bluff is thus the highest in the series. Its position is shown in Bury's map of 1923 [**5**, p. 21]. Eastward the base of the bluff remains near 140 feet O.D. Reid related it to the marine Goodwood Beach in Sussex [**9**, p. 39]. As described by Bury, it is marked by an arcuate ridge, some five miles long, which rises only a few feet above its base from Setley Plain. This ridge may be assigned to the preservative effect of the thick mass of gravel in the bluff.

As in the Lower Thames, the seaward part of the Boyn Hill Terrace of the Solent river does not conform to the regular river gradient, but is longitudinally horizontal. The transverse slope of this part is from 140 to 115 feet O.D.

There is no clear geological evidence that an inter- or pre-Boyn Hill recession [**10**] ever cut back as far as Bournemouth, but unabraded Acheulian in a '15-foot beach' near Portsmouth [**11**, p. 268] and the occurrence of *E. antiquus* and Acheulian implements at 25 feet at Shide in the Isle of Wight [**12**, p. 42] suggest that it was not far away. The general bipartition of the Bournemouth gravels, described by Bury [6, p. 317] parallels the division of the Thames gravels.

THE UPPER TAPLOW OR IVER TERRACE

This terrace was clearly distinguished by E. A. Turner in the Mole [7, p. 48]. Previously it had been treated in the Thames near and above London as one with the Lower Taplow and, below London, as one with the Boyn Hill. About Bournemouth the gravels are usually in continuity with those of the Boyn Hill Terrace, and they were put together by the Survey, except near Lamb's Green, south-west of Wimborne.

The terrace is graded about 30 feet below the Boyn Hill and 20 feet above the Lower Taplow.

The chief development near Bournemouth is north of the Stour, where it constitutes a wide interfluve between that and the Moors river. South of the Stour it occurs at Lamb's Green and near Canford, but farther east has not been found till south-west of Holdenhurst, whence it seems to be nearly continuous to the sea at Southbourne, ranging from 100 to 90 feet O.D. Fragments fringe the cliffs of Bournemouth West and there is a larger patch at Canford Cliff. Along the east bank of the Avon it is cut out for several miles, reappearing about a mile from the coast, which it reaches at Highcliff. As a Solent river terrace it tops the cliffs east of Barton Court and can be followed to the neighbourhood of Fawley, Southampton Water, usually about a mile broad (Fig. 14).

THE FIRST LOWER TAPLOW TERRACE

This, about 50 feet below the Boyn Hill grading, is fairly continuous south of the Stour for seven miles from Henbury to Kinson, but lower downstream is only seen in small fragments. There is more of it, much dissected, on the west flank of the St. Catherine's Hill interfluve. An isolated flat on the east side of Hengistbury Head at 70 feet O.D. obviously belongs to the Avon. The best local example of the terrace is on the east bank of the Avon, where, as the Bransgore Terrace [2, p. 51], it is continuous, apart from small gaps cut by rivulets, for seven miles from Sandford to Highcliff on the coast, with a breadth from half to three-quarters of a mile. At Highcliff the lower edge is at 65 feet O.D. Eastward the equivalent Solent river terrace has been destroyed by marine erosion for three miles. It reappears, west of Milford, and thence runs, diverging from the shore, to Southampton Water, a distance of about 14 miles (Fig. 14). The lower edge descends gradually till it touches the 50-foot contour. The breadth is usually from one to one and a half miles.

It is also found, considerably dissected, in the Moors river country, especially about Ferndown.

In the neighbourhood of Lymington a subsidiary terrace at 81-2 feet, 200-300 yards broad, has been noted for some miles between the Upper and Lower Taplow.

THE SECOND LOWER TAPLOW TERRACE

This was distinguished by White [**3**, p. 56]. But earlier Bury had noted this stage and its importance in the chines [**13**]. The terrace of the Stour is well seen near Knighton, but below that is fragmentary. It is believed to become the flood-plain a mile above Blandford bridge. In the lower course there is the meander core of Berry Hill at 54 feet ; it is found at 50 feet at Southbourne and on the west side of Hengistbury Head, so that the Stour evidently then flowed west of the Head. In the Avon the terrace is seen at North Bockhampton, a mile and a half east of Sopley, and east of Ripley. It comes in strongly a mile north of Pl. 5 and is continuous through Ringwood to Fordingbridge, where it is at 84 feet O.D. Shortly above Fordingbridge it becomes the flood-plain.

This terrace forms the old valley bottom of the chines, as described by Bury, who also noted the beheading of the minor valleys [**14**, p. 77]. An interesting occurrence is in the valley of the Bourne, where it is found at intervals for a mile from the mouth and is then a continuous elevated terrace for three-quarters of a mile, thereafter constituting the valley floors. In the main branch of the Bourne this flood-plain runs up to Canford Heath, where it is abruptly beheaded by rivulets flowing into Poole harbour. The old headwaters of the Bourne, draining the eastern part of the Corfe Hills, are betrunked by a brook flowing into the Stour at Canford.

The Branksome valley is similarly floored and is beheaded near Parkstone Station at about 140 feet O.D. Remarkable is the Luscombe valley, relic of a valley as large as that of the Bourne, of which only a mile is left near the mouth. It is cut off at 65 O.D.

THE BREACH OF THE SOLENT RIVER

The First Lower Taplow Terrace is about 50 feet below the Boyn Hill terrace and 20 feet below the Iver Terrace. It has been traced down to 50 feet O.D. along the Solent river and is there the obvious equivalent of the 50-foot terrace of the Lower Thames. The Second Lower Taplow terrace, 20 feet lower than the First, can be followed to 50 feet O.D. along the Stour, and to nearly as low along the Avon. It is then close to the Muscliff Terrace, a delta which, occurring also in the Frome and Puddle, certainly connected with a sea occupying a bay open to the Channel. It is inferred that the breach of the sea into the Solent river took place during Lower Taplow time. If this is so, the gradient of the Solent-Frome terraces should result in a greater difference of level in the Frome than in the Stour-Avon. Actually the Boyn Hill, Upper Taplow and First Lower Taplow terraces west of Wareham are at levels of 150, 130 and 95 feet respectively whereas the Second Lower Taplow Terrace is at 50 feet. The breach must have taken place near the west of Poole Bay, where the difference would have been about 30 feet.

Waves driven by the prevalent wind have enlarged the opening eastward, but the western Chalk has been in a sheltered position. This location of the breach explains the intensity of dissection round Poole harbour.

THE STAVERTON TERRACE

In 1936 [**1**, p. lxxvi] the writer mentioned a terrace in the Devonshire Dart at Staverton ; and noted that Reid had referred to terraces on the Avon which might be equivalent. Simultaneously, Kirkaldy and Wooldridge had found nicks near 60 feet O.D. in several rivers [**15**]. After seeing Miss Boswell's profile of the Test, closer examination of the Dorset Stour showed that measurements on that river had been too widely spaced and that there was a nick above Wimborne. The Staverton Terrace has usually been overlooked, evidently because most of the elevated part has been buried under the alluvia of the Muscliff delta. It is, therefore, now described in more detail than in the paper on raised beaches [**16**, p. 131].

The development in the Dart, an energetic river, is exceptionally clear. Headward erosion reaches past Buckfast, where it has dug a deep rock channel. The nick is about 130 feet O.D. From Buckfast the flood-plain continues three miles downstream to a nick at 79 feet O.D., and thence the elevated terrace is nearly continuous to 50 feet O.D. north of Totnes. Its occurrence at Staverton has been described in the Survey Memoir [**17**, p. 114].

In the Otter, the head is a little above Tipton at 112 feet O.D. The flood-plain becomes an elevated terrace at Newton Poppleford at about 70 feet O.D.

In the Dorset Frome only a part has been mapped. The villages of East Burton and Wool stand on it. The head is near West Woodford at 127 feet O.D. In the Stour the head is a mile above Blandford bridge at 112 feet O.D. The flood-plain goes to a nick three miles above Wimborne at 70 feet and thence the terrace runs for three miles to Little Canford at 54 feet and Hampreston at 50 feet. It has been followed down to 43 feet half a mile east of Kinson. In the Avon the head is at 104 feet above Fordingbridge, and the lower nick appears to be at 68 feet, three miles north of Ringwood. There is, however, a trench between this and Fordingbridge and the actual position is not yet clear. Immediately north of Ringwood the ‘ 8-foot terrace ’ of Reid is at 58 feet ;

half a mile south of the town his 15-foot terrace is at 55 feet ; and near Bisterne, 2½ miles south, the terrace is at about 53 feet. At this point the Muscliff Terrace is at a level of 41 feet, but wash on it rises towards a sharp little bluff four feet high, so that it obviously fills a valley eroded in the older Staverton Terrace. Near Ripley the height is 45 feet.

The terrace occupies much of the valley of the Moors river as far as Verwood, north-west of Ringwood. It floors a considerable part of the Bourne. It has not been noticed along the Solent.

THE UPPER BURIED CHANNEL AND MUSCLIFF TERRACE

Between the lower nicks just described and the heads of the Muscliff delta are flood-plains graded to some level below Ordnance datum. The Muscliff Terrace is excellently displayed near its name-place, where it maintains a constant height of 41 feet and is undissected, owing to a shift of the Stour. For over four miles along the river no evidence has been found for change of level ; then a gradual rise begins, which attains the nick west of Wimborne in another five miles. Similarly in the Avon the terrace maintains the same level for five miles from a point about two miles north of Christchurch. Two miles north of St. Catherine's Hill the Muscliff terraces of the Moors and Avon are confluent, so that it would seem that formerly the Moors joined the Avon, not the Stour. Much of the Stour-Moors interfluve is made of this terrace.

Observations on growing bay-deltas suggest that the foreset beds accumulate up to the level of high-water spring tides. Information is lacking on the point at which ordinary fluviatile aggradation begins, but it seems probable that it is near tide-head. On the present delta of the Frome, there is not more than a few inches variation till Wareham, a little below ordinary spring-tide head and two miles above the delta face, and apparently the rise does not begin till a mile farther upstream, but this has not been measured. The places where the level begins to rise are taken as the limits for the portions of flood-plains assigned to the 'Upper Buried Channel,' which is considered proved to be earlier than the Muscliff delta by the depth of 33 feet of gravel proved at Chertsey [**18**] and by records in the Dart estuary.

The terrace occurs in the area of the map (Pl. 5), but has not been separated.

THE CHRISTCHURCH TERRACE

A mile and a quarter south of Muscliff the 41-foot terrace begins to drop gently, ending at a height of about 33 feet O.D., from which a definite bluff falls sharply to a lower terrace at 22-23 feet O.D. Up the rivers the same gradual fall to a bluff is found The origin of this terminating slope of the delta has not been determined, but it has been mapped as part of the Muscliff Terrace.

The most notable relic of the 23-foot terrace is an interfluve, two miles long, between the Stour and Avon, on which much of the town of Christchurch is built. There is a fine coast section of the gravels, nearly a mile long, between Southbourne and Hengistbury, at both ends of which the valley side is seen plunging steeply. Along the Stour the terrace goes to a head at Canford, two miles below Wimborne, at a height of 50 feet O.D. It is well preserved in the Stour-Moors angle. In the Avon the head is at 55 feet O.D., a mile north of Ringwood.

A still later rejuvenation heads in the Stour at Longham at 34 feet O.D. In the Avon it heads about 33 feet O.D. at Watton's ford, a mile and a half north of the area shown in Plate 5. It has been mapped for two miles downstream, but its relations with lower terraces have not been settled. It appears to plunge under a 10 feet terrace developed round Christchurch harbour.

THE HORIZONTAL SEGMENTS

Most of the terraces end seaward in a segment, longitudinally horizontal. The curves adjusted to flood-plains above these segments meet them at an angle, as if graded to some lower level. The heights of the inner edges are approximately, Ambersham, 190 feet ; Sleight, 165 feet ; Boyn Hill, 115 feet ; Upper Taplow, 90 feet ; Upper Buried Channel with Muscliff, 41 feet. A horizontal segment of the First Lower Taplow at 50 feet is believed to begin halfway between the Lymington and Beaulieu rivers, but this needs verification.

Horizontal segments are also found in the River Dart. The geomorphology of the Lower Thames is little known, but there is a long horizontal segment of the Boyn Hill and probably also of the Lower Taplow [**19**].

The Muscliff Terrace, an obvious delta, is certainly due to a considerable rise of sea level, but the older examples have a solid base to the gravels which, as far as the writer has been able to ascertain, is at least nearly as horizontal. In the Dart a horizontal segment is found in the Sicilian Terrace on a large scale, which also seems to be non-deltaic.

At the present period of marine instability, in which our rivers are only beginning to fill up their drowned valleys, a discussion of the effect of a long standstill must be theoretical. On general grounds it is likely that in such a case combined marine and fluviatile action would produce a horizontal segment. Wave action at highwater can be seen in our estuaries ; at low water the rivers meander in the sand and mud of bottomset beds. This hypothesis supposes rivers to have meandered formerly in a tidal course on a bottom predominately solid. The writer is not aware of any such occurrence at the present day.

No geological evidence has been found for a rise of the sea above any of the post-Sicilian terraces. Their form suggests that they have not been worked over by an advancing or retreating shoreline.

CORRELATION

The 300-foot terrace has been satisfactorily correlated with the Sicilian by Bury. It is equivalent to Bull's 320-foot bevel in the South Downs [**20**]. The terrace next above it, found near though not in the Bournemouth area, was connected with the Cornish ' 430-foot platform ' by Bury [**5**, p. 28]. It is equivalent to Bull's 400-foot bevel. The deposits on it have been shown by Dr. Solomon [**21**] to be the Westleton Beds of East Anglia.

The most fully described district of the Middle Thames is near Iver [**23**]. The spacing of the terraces corresponds well to that at Bournemouth. They can be compared as follows :—

IVER	BOURNEMOUTH
Pre-Boyn Hill	Ambersham
Upper Boyn Hill	Sleight
Lower Boyn Hill	Boyn Hill
Iver	Upper Taplow
Taplow	Lower Taplow

If this correlation is accepted, it will be convenient to use the name ' Iver Terrace ' for the feature otherwise termed ' Upper Taplow Terrace,' and to restrict the name Taplow to the lower Terrace, as suggested by Dr. Arkell [**16**, discussion, p. 120].

In the Lower Thames the morphological terraces are so little known that comparisons are difficult. Hinton and Kennard in 1905 wrote [**24**, p. 80] " the highest terrace . . . . is well seen at Dartford Heath, 136 ft. O.D., and Dartford Brent, 131 ft. O.D. . . . . The well known terrace at Greenhithe and Northfleet, 100 ft. O.D., must be considered as belonging to a later stage." In 1912 Chandler and Leach [**25**, p. 104], finding no difference in the levels of the solid bases of the terrace-gravels at Dartford Heath and Milton Street, considered that the distinction could not be maintained. There is not, however, any reason why terraces, distinct morphologically, should not have the same gravel base locally, especially if measured in bluffs ; and a terrace-gravel may rest on an older gravel. The views of Hinton and Kennard are equally applicable to the Bournemouth rivers.

In 1913-14 Dewey and Smith [**26**] published the results of investigations at Swanscombe. The morphology was not described and it has not been practicable to revisit the locality, but comparison with the six-inch maps suggests that the excavations were not conducted in one terrace. The Barnfield pit is obviously driven into the bluff of a high terrace, but it would seem that the actual terrace surface, which is apparently about 125 feet O.D. was not reached, as the highest level shown in the pit was 110 feet O.D. The 'Upper Gravel' is a wash, evidently channelling the bluff, but there is also a development of the Upper Gravel in the neighbouring Milton Street pit, the surface of which is shown at 104 feet O.D. and is nearly flat. There are then two terraces concerned, the lower being the Upper Taplow or Iver terrace. Most of the gravels do not seem to belong to either terrace, but to older bay-deltas.

Galley Hill, where the well-known skeleton was found [**27**] is a flat just below 100 feet O.D. and is clearly Upper Taplow with superficial brickearth. In 1928 Dewey wrote [**27a**] that there were two ledges in the solid rocks, with alluvial deposits sweeping across both. About Grays the maps indicate a spread of gravel to the west at 113 feet O.D. with the base of the gravel a little over 100 feet O.D. [**28**, p. 97]. To the east the stretch of gravel through Chadwell to Tilbury is partly just over, but mostly slightly under 100 feet; the gravel base is at or below 80 feet. The surface measurements correspond closely with the Boyn Hill and Upper Taplow terraces of the Solent river.

The terraces of the Warwickshire Avon and the Severn, being in glaciated country, may not compare closely with those of Bournemouth. But in the Avon [**29**] terrace No. 4 resembles Boyn Hill; while Nos. 3 and 2 resemble Upper and Lower Taplow. The Kidderminster terrace of the Severn is correlated by Wills with Avon No. 4 and Boyn Hill [**30**, p. 230]; and the Main terrace, correlated with Taplow, is double, at least in places, and is held to be equivalent to Avon No. 2 and probably No. 3 [**30**, p. 198].

Breuil and Koslowski [**31**] assign four terraces to the Somme at Amiens. Their levels, in metres above the thalweg, are given as: Plateau, 55; High Terrace, 40; Middle Terrace, 30; and Low Terrace, 10. These are only to the nearest five metres and appear to be taken at the middle of the gravels. From Fig. 3 (after Commont) the surface levels at Amiens might be about 69, 55, 46 and 33 metres above mean sea-level; i.e., 226, 180, 151 and 108 feet. For a base level at 31 feet above the sea these figures reduce to 195, 149, 120 and 77 feet, much like those of the Bournemouth Ambersham, Sleight, Boyn Hill and Lower Taplow terraces.

A late account of the lower terraces of the Lower Thames, by King and Oakley [**10**] distinguishes Taplow, Upper Flood Plain Stages 1 and 2, Halling or Lower Flood Plain Stage and Tilbury Stage, but not on morphological grounds. Correlation of the Staverton, Upper Buried Channel and Muscliff terraces has been discussed in a previous paper [**16**]. The Christchurch Terrace, judging by the slight rejuvenation of the brooks across the Muscliff delta and the brevity of its cut back in the Stour and Avon, must be very recent geologically. It seems to correspond to the six-metre beach of Daly [**32**]. It is well developed in the

Dorset Frome. A terrace is found on both sides of the Dart at Totnes with level 21 O.D. The lack of Thames measurements makes any comparison doubtful, but it may be equivalent to the fourth terrace of Hinton and Kennard and to Upper Flood Plain Stage 2. In 1925 G. E. Hutchings described a 25-foot terrace of the Medway as identical with Hinton's fourth terrace [**33**].

THE SLOPE OF THE TERRACES

The slope of a terrace may be analysed into two components : one parallel to the general trend of the valley, the other, transverse to it. The former, the longitudinal slope is best dealt with in relation to a larger area than that considered in this paper.

The existence of the transverse slope towards the inner valley, which is obvious over Southern England, seems to have been accepted by British geologists as normal and has not, as far as has been ascertained, been discussed. In 1936 the writer referred to such a terrace as an ancient flood-plain [3, p. lix]. On this Prof. C. A. Cotton, whose views command respect, has commented [**34**, p. 36]:

> "Systematic concavity of an actual flood-plain is inconceivable. Both degraded and aggraded flood-plains are, except for minor irregularities, faintly convex."

It cannot be said that the generalisation that a flood-plain, even if defined as the plain actually liable to flooding today, is convex, is of universal application. In this country it can sometimes be seen that a flood, as it rises, spreads farther from the river, so that the area covered must be concave. The valley-plain[1] continues the concavity.

Along the Poole-Ringwood road the Ambersham Terrace falls 16 feet towards the Solent river in 1.2 miles. The Boyn Hill near Bournemouth shows falls in places over 15 feet. The Upper Taplow falls 12 feet. The First Lower Taplow consistently falls about 18 feet. There is a considerably body of evidence to show that these transverse slopes are only partly due to wash. The difference of level between inner and outer edges is independent of the slope of the terrace. It is, for example, the same on Bracklesham Sand and Barton Clay, though the slope of the terraces differs. The slope persists in areas where wash could not form. Thus the Boyn Hill plain in the angle between the Stour and Solent rivers (Pl. 5) has a parting three miles long between the rivers, which, a mile from the termination of the Sleight Terrace, is at 134 feet O.D. As noted by Bury, the terrace falls from this to 120 feet O.D. towards the Stour and to 124 feet O.D. towards the Solent river, in each case about a mile. Wherever evidence is available, the solid base of the gravels is found to slope not much less than the surface. Examples have been mentioned by previous writers [**6**, p. 317 ; **3**, p. 52].

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[1] Why is this curious term used now instead of Lyell's 'river plain'?

If a graded portion of the profile be conceived, not as in equilibrium, but as in motion, then lateral and downward erosion must be simultaneous over much of the course, thus producing a 'staircase,' like the 'polygenetic terrace' of Chaput [**35**]. To obtain some conception of the surface to be expected theoretically, take the time elapsed since the opening of the Boyn Hill standstill to be 360,000 years [**36**] and suppose that 120,000 years ago the Boyn Hill rejuvenation had reached 36 miles from the mouth, the total headward erosion during the last 120,000 years being 12 miles. This rate seems reasonable, in view of Bromehead's measurement of the recession of a nick in the River Wharfe [**37**], equivalent to eight miles in 120,000 years. Then, on assumptions based on known measurements, the downward erosion at 30 miles from the mouth would be 12.4 feet. Other assumptions yield results up to 35 feet. (Appendix.) It is not pretended that the calculations do more than show that theory gives depths of magnitude comparable with observation.

Though the rate of advance of meanders in alluvium is often referred to as 'rapid,' measurements admitting an estimate of the time taken to pass twice a given point are not easy to find. Between Wandsworth and Kew the modern gravel of the Thames is in places in juxtaposition with calcreted older gravel [**38**]. Mr. A. S. Kennard informs the writer that, from the associated fauna and artifacts, it is older than the early Bronze period and is probably of Atlantic age, 4000 B.C. At Ribchester an advancing meander of the river Ribble has destroyed 150 yards of the south-east defences of the Roman fort, which was occupied till near the end of the fourth century. As the fortifications are approximately parallel to the alignment of the river, and the meanders average about a mile apart, this suggests a limit of not more than 18,000 years. If in the theoretical example the interval between passages is taken as 15,000 years, the staircase would have eight rises, averaging a foot and a half. Rain, soil-creep, vegetation, aeolian deposition, etc., would obliterate rises of considerably greater height, so that the result would be a terrace resembling those of Bournemouth. And since floods may rise several feet, a concave flood-plain is explained. Thus the terraces of Southern England may be considered to be integrations of numerous partial flood-plains. Gilbert's dictum "River terraces . . . . are always the vestiges of flood-plains" [**39**, p. 132] is apposite ; and his definition of *flood-plain* (p. 127) is consistent with a plain swept out by repeated meanders.

It is not suggested that Prof. Cotton's opinion is inacceptable when applied to New Zealand terraces, which, judged from the photographs which adorn his works, are unlike those with which the writer is familiar. Perhaps this is due to the notorious instability of New Zealand compared with the long stability of most of England.

This explanation also accounts for the predominately gravelly nature of the terrace-veneer. Gravel is laid down in the river channels, while simultaneously silt and clay are deposited on the flood-plain and in oxbows. Repeated washing by sweeping meanders would eliminate most of the finer material.

The above analysis does not apply to the horizontal segments, which also show marked transverse slopes. The Boyn Hill Terrace falls 25 feet, and, in the only case measured, its gravel-base falls at least 17 feet. But similar results would follow a slow fall of sea-level, for which there is independent evidence at the Goodwood end of the terrace [**40**].

THE BLUFFS AND THEIR GRAVELS

The slope of the bluffs or rises varies with the nature of the solid rock underlying the gravels. Though there are no such spectacular changes as those which are seen, for example, on the river Bovey when it passes from Palaeozoic rocks to Bovey clays, differences of some importance are found near Bournemouth between the slopes above the Bagshot Sands and those above the softer Headon Beds.

On the former, and on the Bracklesham Beds, the bluffs between consecutive terraces above the Lower Taplow have slopes, measured on the mapped edges, from one in 30 to one in 20. They are easily seen on the ground. The highest, the Sleight-Boyn Hill bluff, may show a steep part, about one in 8. Two bluffs on the Barton Sands are about one in 30. But on the Headon Beds, mostly clays, the only bluffs between consecutive terraces with a slope of more than one degree belong to the highest bluff ; the slopes noted in it approximate to one in 45. The others are from one in 70 to one in 120, and the writer has not been able to follow them by eye.

Bluffs to the Second Lower Taplow on sands are steeper, often one in 10. But a bluff between the Second Lower Taplow and the Staverton, on Barton Clay, is about one in 70. Later bluffs are often immature in appearance.

Thus the construction of a river terrace bluff, even on sands or clays, must be spread over a considerable period ; a conclusion of importance to gravel studies, since the majority of gravel-pits are in, or started in, bluffs. A count of pits marked on the six-inch maps near Bournemouth, on which terraces have been discriminated, yielded 110 opened in bluffs, nine apparently sunk in the surface, and 10 doubtful. The economic convenience of thus securing drainage and access is obvious ; and greater thicknesses of gravel are obtainable.

The formation of a bluff begins with a river-cliff cut by the outer bend of a meander. The Bournemouth sands will hold steep slopes for some years. The only slope actually measured within a bluff (at a pit by Poole Lane, West Howe) was one in three. As the meander sweeps on, a veneer of gravel is deposited. The cliff crumbles into a mixture of tumbled sand and older terrace gravel. In the earlier stages slumping may produce contortion. As the slope of the bluff diminishes, material washed down on it may be expected to appear nearly horizontally bedded. On reaching stability the result will be as in the diagrammatic section, Fig. 15, in which the transverse slope of the terraces is taken to be one in 200, of the bluff AB one in 25. The terraces differ in height by 30 feet and the thickness of each terrace-gravel is eight feet. A later bluff cutting the older is suggested by CD. When an unusually large amount of gravel is needed, a convenient point of entry would be at X. The available thickness of gravel shown is over 20 feet.

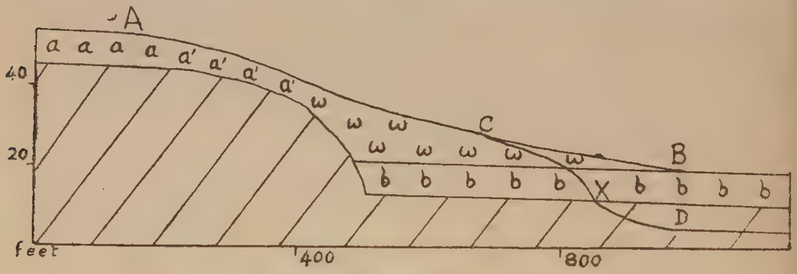

Fig. 15.—Diagram of Bluff.

a. Upper terrace-gravel, a′ disturbed terrace-gravel.
b. Lower terrace-gravel, w. Talus and wash.

The presence of a steep internal cliff, against which gravelly talus abuts, can be seen in several places in the Bournemouth cliffs. The section of the First Lower Taplow–Christchurch bluff near Highcliff has been figured by White [2, p. 58]. The upper gravel in pits of this type is composed of a mixture of country rock, river gravel and superficial material, from which some of the finer debris has been eliminated to form a thin wash beyond the coarser gravel. It has often been supposed to be a glacial or fluvio-glacial deposit. The most striking example known to the writer is the pit at Broome, in the Axe valley. It is hoped to give accounts of this and some other pits in a separate paper.

In connection with correlation with the Lower Thames, it may be observed that, owing to the greater breadth of the terraces and the presence of a mantle of brickearth, Thames bluffs on London Clay are probably less easy to see than those of the Solent river on Headon Beds.

DEFERRED JUNCTIONS AND MINOR DIVERSIONS

A deferred junction of the Solent and Stour was suggested by Bury [**14**, p. 77]. While it is clear that the junction moved some way downstream during the Ambersham stage, the extent of the movement has not been determined. It may have been about three miles. The actual junction of the Sleight terraces is at West Howe, and of the Boyn Hill terraces a mile east of Talbot Village (Pl. 5), having thus travelled two miles downstream. The south-eastern termination of the Boyn Hill Terrace has been destroyed by marine erosion ; it was probably about half a mile south of the present cliff, halfway between Boscombe and Southbourne, having travelled some three and a half miles. The lie of the Upper Taplow terraces suggests that their junction was not much farther downstream, perhaps three-quarters of a mile.

A submarine ridge, well marked by the 5-fathom contour, runs south-east from Hengistbury Head to die out against a deep which lies within a ridge westward from the Needles. The deep may mark the site of a stream flowing during the buried channel episodes. In First Lower Taplow time the Avon and the Stour would have flowed respectively east and west of the Hengistbury ridge to the Solent.

During the deposition of the Christchurch terrace the Stour wandered eastward to join the Avon. The Moors took the opposite course, leaving the Avon to join the Stour.

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APPENDIX

Parameters of Boyn Hill terraces are known in the south of England from 65 feet to at least 600 feet. For the present purpose a parameter is assumed as 100 feet, when the curve fits a height of 100 feet at 36 miles from the mouth. Taking the point at which the stream reaches sea-level as origin, the equation is $y = —100 \log (1—x/40)$. At 30 miles the height above sea-level is 60.2 feet.

As a river cuts back, the profile flattens, that is, the parameter increases. The simplest relation would be for the parameter and the asymptotic distance from sea-level to vary *pari passu.* The form of the curve in such a case would be $y = —ap \log (1—x/p)$, where a is constant and p some function of the time.

On this assumption a terrace 45 feet higher at the mouth, cut into by the Boyn Hill at 100 feet, 36 miles from the mouth, would be represented by the curve $y = 45 — 174.2 \log (1—x/69.68)$. If the Boyn Hill stage continues to cut back in this higher terrace to 48 miles from the mouth, its profile would become $y = — 133.3 \log (1—x/53.32)$, and at 30 miles the height above sea-level would be 47.9 feet, so that the downward erosion at that point would be 12.3 feet.

This conception, which treats the profile as in motion, is inconsistent with a ‘profile of equilibrium,’ as usually defined. No doubt a different form of equation would be required for rivers under a climatic regime differing from that of England.

The above calculation assumes that the mouth, taken as the point at which sea-level is reached, remains constant in position. If, however, we suppose that, while the Boyn Hill stage was cutting back from 36 to 48 miles, a delta had shifted the mouth six miles outward, the new profile would be $y = 282.9 — 157.3 \log (56.92—x)$ and erosion at 30 miles from the old mouth would be 2.2 feet. If the sea had worked inward six miles, the new profile would be $y = 185.6 — 112.3 \log (50.92—x)$ and the erosion at the same point 22.9 feet.

A DETAILED PROFILE OF THE RIVER TEST

By KATHARINE C. BOSWELL.

With an Interpretation by J. F. N. GREEN.

THE preparation of a detailed profile of the Test was first suggested by a study of the exact measurements on which a paper by Sir C. Close on the river Itchen was based [1*]. It was hoped that a precise description of the form of one river would be of assistance to those who were already working on the development of drainage in this country.

The survey was made with dumpy level and target staff, working along stretches of the river from one Ordnance bench-mark to another. When closure was unsatisfactory, the measurement was repeated. Difficulties occasionally occurred owing to alterations in bench-marks—one had actually been rebuilt to a different level ; but it is believed that, with the kind assistance of the Ordnance Survey Levelling Department, all have been solved. In the field, measurements were made to hundredths of a foot. The height recorded is to the nearest tenth. A great deal of help was received from students of Southampton University College, especially from Messrs. T. Redford and K. C. Russell at the beginning, and later from Mr. A. Skeet, without whom the practical work would never have been completed.

Most of the measurement was made to the water surface, though a number of levels were also determined on the assumed flood-plain near the stream. No doubt geomorphologically the river edge of the flood-plain is the feature for consideration. But the Test flood-plain near the stream has been so much interfered with (banked up for fishing paths or trodden down by cattle, and occasionally overgrown with vegetation) that its true level is often uncertain. Where there is a marked difference between water level and flood-plain on either bank of the river, the beginnings of an elevated terrace may sometimes be inferred, and Mr. Green has made use of such levels in his notes.

The levelling was carried out in 1937 and 1938, times of flood being avoided, and it is probable that the surface varied only slightly from the average summer level. Actually throughout the whole period only 5 inches variation was observed on a gauge post near Longstock weir.

The bottom of the river is very uneven, so that it did not seem a useful surface to plot. The water is often 2 to 6 feet deep, but there are holes said to be over 17 feet deep.

There has been much interference. More than 50 mills are mentioned in Domesday Book, and at the present day mills and weirs, usually for water-meadow irrigation, are found in every

[*] For List of References see pp. 106 and 115.

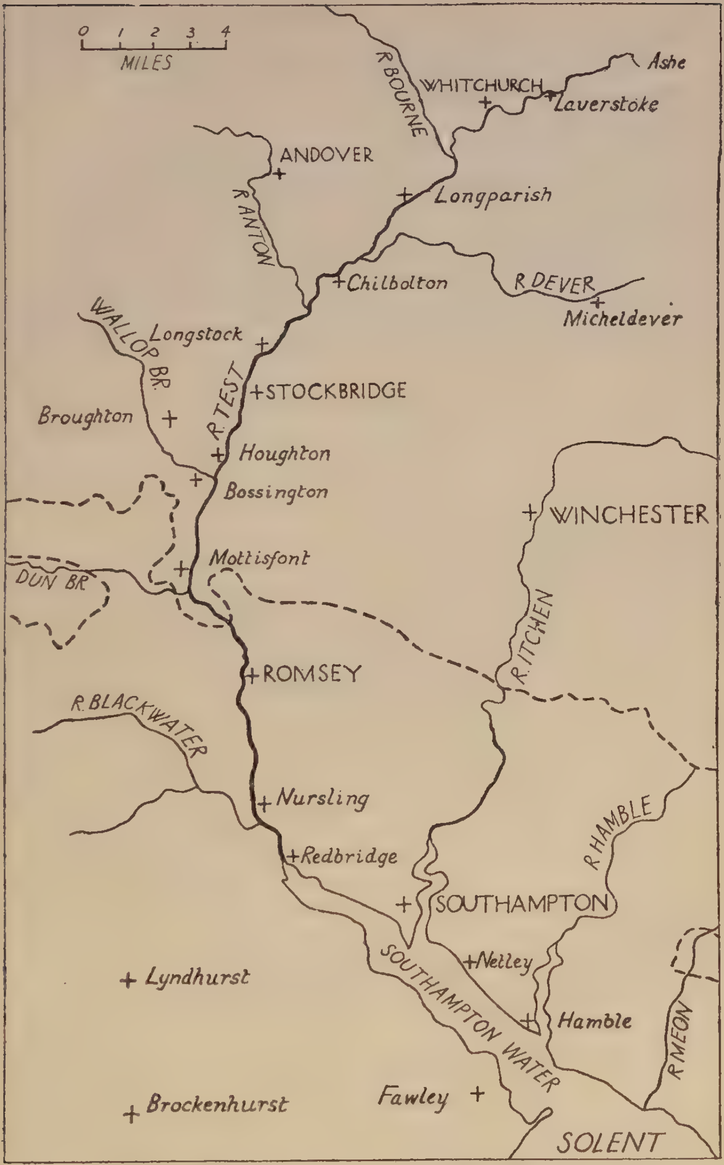

FIG. 16.—MAP OF THE RIVER TEST.
The broken line marks the boundary between Chalk and Tertiaries.

part of the river. In places the stream has been diverted from its natural course by cuts.

Horizontal measures were made along the winding stream, as shown on the six-inch maps, from a zero point taken at 700 feet above Redbridge.

Terraces and platforms have not been surveyed, but a considerable amount of information has been collected from (1) the Memoirs of the Geological Survey on Sheets 283, Andover ; 299, Winchester ; and 315, Southampton ; (2) an examination of the manuscript six-inch maps of the district in the library of the Geological Survey ; (3) a series of cross sections of the valley based on the 1/2500 maps, much of this work was done by Mr. Skeet— ; (4) some of the flood-plain levels which showed an unusual height above the water surface ; (5) personal observations of flats and bevels near the river.

The Test is a small river, 37 miles long as measured along the windings and about 31½ miles along the central line. It is steep for a south-eastern river, falling 290 feet. The source is in a dry valley of *cor-anguinum* Chalk. First flowing west-south-west in a narrow but fairly open valley for 8 miles, it turns south-west at confluence with the Bourne. It flows in this direction for 9 miles to the neighbourhood of Stockbridge. The first 4 miles of this part of the valley is shallow and open, of mature appearance, but south of the junction with the Dever it becomes narrow, straight-sided and deeply incised. A mile north of Stockbridge the valley turns south-south-west and continues with the same incised form for 6 miles to Mottisfont, where the Chalk passes under the Reading Beds. A sudden change of direction of the valley to south-east suggests that formerly a greater flow of water came down the Dun valley, which occupies a syncline and enters just south of Mottisfont. The main valley resumes a southerly course in about 2 miles, but, after following this for 5½ miles, again turns abruptly south-east near the junction of the Blackwater, that is, about a mile above tidehead. In the days of the Solent River, this south-east direction was continued for some 14 miles to the junction. The valley is wider and the slopes gentler in the Tertiaries than in the Chalk, but in its northern part less subdued than in the Chalk section near the Dever junction.

The course from the confluence with the Bourne is against the grain of the country. It crosses the *Uintacrinus* zone brought down by the Micheldever syncline and passes over *cor-testudinarium* Chalk brought up in the Stockbridge anticline. Then it crosses higher zones to the northern edge of the steep Alderbury syncline, which brings in the Tertiaries.

The final profile was plotted by drawing a smooth curve through the river level just below weirs (presumed to be approximately the natural level) and the points above the artificially raised sections.

Inspection of this profile shows that sections of it fall on smooth curves which are presumably graded. Between these are in many cases more irregular sections, of which the most remarkable is that from Mottisfont to Timsbury, immediately below the junction of the Chalk and Tertiary. These irregularities have caused some difficulty in determining the nick-points. By making a list of the gradients, these were found to vary from more than 4 per mille above the confluence with the Bourne and below Houghton to 0.3 per mille above Timsbury and 0.9 per mille above Longstock mill. Even as near the mouth as Nursling mill a gradient is 2.7 per mille. From consideration of the gradients nicks were thought probable at 290 (source), 263, 238, 192, 169, 150, 135½, 115, 100, 74, 60 and 28 feet above sea-level, with a doubtful one at 206 O.D. These compare well on the whole with those proposed by Wooldridge and Kirkaldy [**2**].

The highest platform above the valley sides is prominent at 550–560 O.D. Examples are Woolbury, above Stockbridge; Quarley Hill, west of Andover; Farley Mount, west of Winchester; and summits above Popham Beacon. This is the Pliocene planation of Wooldridge and Linton [**3**] and corresponds to that part of the planation provisionally assigned to Casterlian-Scaldisian by Green [**4**]. Bevellings at 430–470 feet on spurs from the higher summits, and some isolated hills like Danesbury (470 ft.), indicate a lower platform. A gentle slope or flat at 370–400 feet is prominent behind Compton House, South of Horsebridge; on a spur from Farley Mount; and on Cowdown, 3 miles west of Longparish. A beve at 330–350 feet is well developed in the Andover-Broughton district and extends to the neighbourhood of Houghton. It continues to a platform which is from 280 to 300 feet between Houghton and Mottisfont and forms the gravel-topped Tertiary summits further south at 270 to 280 feet. Mr. Green considers this to be obviously the marine platform near 300 feet found in neighbouring areas by Bury [**5**], Bull [**6**] and himself [**7**], which is regarded as Sicilian. Part or all of a platform found between Longparish and Testcombe at 270–280 feet may however represent the upper part of the Ambersham terrace, which occurs as a 200-ft. terrace on the Tertiaries, rising to 220–230 feet between Mottisfont and Houghton, and to 230–250 feet north of Stockbridge. The lower terraces are detailed by Mr. Green in his appended notes.

I have already acknowledged the great help in field work which I have received from students. Riparian owners were so good as to arrange days when we might work on their property. Dr. J. F. Kirkaldy and Mr. Robert Aitken have been most kind in giving advice and information; while Mr. Green's aid, especially in helping to sort out the platforms, has been invaluable.

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APPENDIX

Numerical data

Distance from point 700 feet above Redbridge road bridge. In hundreds of feet (x)		Water level above Liverpool datum in feet (y)
Datum		
44	Testwood House sluice gates	4.1 & 7.3
54		7.8
79		8.4
88	River Blackwater enters	
91		9.1
103		10.6
108		10.8
117		12.4
122	Nursling mill weir	13.6 & 17.2
137		17.8
149		18.9
160		19.8
177		22.0
185		23.9
200	Opposite weir	26.5
203	Long bridge, Lee	26.5
203	Gauge post. Extremes noted, 1½ above zero to 5½ below	
212		28.2
228?	Smooth water above Skidmore rapids	29.0
245	Footbridge	30.1
281		31.4
300		33.4
304		34.1
309		34.8
312	Middle bridge, Romsey. Enter Tadburn Lake and Pauncefort Hill stream	35.3
322	Sadler's mill	35.9 & 41.2
340		42.1
355		44.0
361		44.4
371		45.6

Distance from point 700 feet above Redbridge road bridge. In hundreds of feet (x)		Water level above Liverpool datum in feet (y)
382	Duck pond	47.2
390		48.7
397	Railway bridge	49.8
400		50.4
406		53.0
415		55.1
416		55.7
417	Great bridge, Romsey	55.9
430	Timsbury old bridge. Enter Fairbourne and Stansbridge Earls brook	59.5
440		60.1
458		60.2
473		60.7
489		61.0
494		61.4
516	Shallow	62.1
	Rapids	
517	Shallow	63.3
526		65.0
532		65.4
536		66.9
551	Kimbridge	68.5 & 69.4
	Above mill dam. Entry of Dunwater (now prevented)	73.1
588	Mottisfont bridge	73.6 & 74.4
642	Lower Brook bridge	75.7 & 77.4
670	Rapids	79.0 & 79.8
675		80.3
696	Below Compton Estate weir	80.6
708	Cattle ford	82.8
718	Power House, Pittleworth	83.2 & 88.7
737	Enter Somborne	89.2
752	Bossington cattle bridge	89.5
759	Bossington weir	90.1 & 93.9
774	Enter Wallop Brook	94.1
779	Houghton Mill	96.4 & 97.7
799		98.8
802		99.1
809		99.8
820	Houghton, opposite N. end of island	100.9
829		101.2?
855		101.9?
861		102.8?
870		104.0
882		105.4 & 108.4
893		108.7
903	Dairy Farm bridge, Houghton	109.2
913		109.9
926		110.3 & 113.2
937	Stockbridge, at road bridge	113.0
950	Longstock mill	115.4 & 118.7
978		119.5
988		120.0

Distance from point 700 feet above Redbridge road bridge. In hundreds of feet (x)		Water level above Liverpool datum in feet (y)
1001		120.4
1013	Longstock weir	121.6 & 122.5
1031		124.6
1092	Leckford	128.2
1102	Waterwheel, Longstock Manor	128.7 & 130.2
1127	Enter River Anton at 1108 and 1128	130.8
1131	Seven Stars, Fullerton	132.0 & 133.2
1138	Railway bridge, Fullerton	133.8
1156	Testcombe	135.5
1198	Westmill bridge, Wherwell	137.8
1223	Manor Farm, Chilbolton	142.3 & 144.0
1244	Wherwell Lodge	145.7
1259		147.7
1268		149.5
1272	Junction of River Dever	150.1
1283		151.5
1286		151.7
1290		152.4
1295		152.8
1319	Dodmoor Great weir	155.9 & 156.9
1330?		157.7
1354	Gavelacre	161.3 & 162.6
1363		163.0 & 163.7
1370	Basingstoke-Andover road, Forton	165.6
1371	Weir above road bridge	165.9 & 166.7
1381	Footbridge	168.0
1382		167.9
1387		169.3
1392		170.3
1393	Longparish saw mill, Forton	170.4 & 173.2
1409		173.7
1411	Cattle bridge near Longparish Church	174.1
1420	Bridge to South Side Farm, Middleton	175.1
1436	Longparish Lower mills, under road bridge	178.3
1443	Lower mill	180.5 & 182.3
1477	Upper mill, Longparish	184.8 & 188.2
1488	East Acton (bridge)	188.3
1492		188.5
1507		190.2
1521	Junction of Bourne and Test	
1524		192.5
1530	Bridge at end of grounds	193.4
1536	Testbourne weir	194.0 & 197.5
1543	Papermill bridge	198.5
1554	Footbridge	202.8
1556	Weir	203.0 & 203.5
1558	Weir	203.6 & 204.1
1565	Footbridge	205.6 & 206.2
1575		207.0
1577	Weir	208.0 & 209.2
1584	Below footbridge near railway bridge	209.7
1588	Opposite Tufton Farm	210.0
1599	Junction of stream and mill tail of Fulling mill	211.7

Distance from point 700 feet above Redbridge road bridge. In hundreds of feet (x)		Water level above Liverpool datum in feet (x)
1600		212.7
1608		214.2
1612	Fulling mill, Whitchurch	216.4 & 218.4
1621	Footbridge near Church	218.7
1632	Whitchurch Silk mill	219.8 & 222.2
1633	Whitchurch Great Town bridge	222.2
1647	Town mill, Whitchurch	222.7 & 227.5
1672		227.5
1698	Below Bere mill	232.6
1701	Above Bere mill	236.6
1716	Footbridge	237.3
1749	Freefolk bridge	240.9
1762	Laverstoke Mill	
1777		248.2
1778	Bridge from lodge, above millpond	248.3
1792	Slight rapid	248.6 & 249.3
1794	Bridge from other lodge	250.4
1802	Pump House fall, Laverstoke	250.9 & 253.3
1810	Ford below Northington Farm	253.3
1818	Weir opposite Northington Farm	255.6 & 256.4
1827	Lynch	256.9
1834	Bridge on Parsonage Farm	262.6
1847	Southington Silk mill	263.2 & 267.9
1861	Overton Rectory bridge	268.4
1899	Quidhampton mill	274.1 & 279.8
1922	Bridge above Kennels	282.7
1944	Polhampton. Warden footbridge above ford	285.6
1953		287.0
1964		288.0
1972	Ashe. Spring	289.6

INTERPRETATION

By J. F. N. GREEN

It should be understood that the whole of the facts discussed in these notes have been collected by Miss Boswell and her assistants. The only part of the river Test with which the writer is acquainted is that about Mottisfont and Timsbury at the mouth of the Dun valley.

An analysis of the profile was made by fitting logarithmic curves to the sections which had a graded character. In doing this it was necessary to make allowances for artificial interference. In the case of weirs and mills, the levels taken below the fall were found to give the best results, variation on either side of the closest curve being almost identical. Several levels are evidently affected by local aggradation due to silting-up above weirs or in millponds. Such deviation is marked above Laverstoke and Bere mills and above weirs some two miles above Mottisfont. Bridges sometimes have an effect in holding up water comparable to a weir.

In what follows, it is often convenient to specify places along or near the river by the number of hundreds of feet from zero datum in Miss Boswell's horizontal measurements, i.e., by x in the curve. Both horizontal and vertical measurements can be cited in this way, e.g., Middle bridge, Romsey, as 312/35.3.

The highest part of the profile, for a mile, does not differ by more than .3 ft. from a straight line with a gradient of 1.4 per mille. This is probably graded to the Ambersham Terrace.

From 1861 to 1698, a reach of over 3 miles, the stream is graded. Omitting the bridges at 1834 and 1716 and two levels at 1777–8, on a silted millpond at Laverstoke, 10 water levels remain, which can be satisfied within .8 ft. by a series of logarithmic curves with parameters[1] from 70 to 110 feet. A terrace at about 170 O.D. occurs for several miles near Romsey, the most northern portion being at Awbridge Farm, between Kimbridge and Timsbury, at about 510. On the farm is a benchmark 170.6 O.D. All the series of curves come nearer to this than to any other terrace, the extreme measurements on them being 178.5 and 157.0. The median curve $y = 451.5 - 90 \log (1970 - x)$ fits the profile to .6 ft. and gives 166.8 at Awbridge Farm. Although extrapolation is nearly 23 miles, such a wide range justifies tentative attribution to the 170-ft. terrace. This is undoubtedly the equivalent of the Sleight Terrace, mapped for miles along the Solent at the same height.

At 1658 the stream, where held up by the Town mill, Whitchurch, cuts into a terrace with a height of 231.2 feet ; the median curve gives 227.0. A mile downstream the terrace is 10 feet above the river. Terraces about 200 O.D. are recorded east and south of Chilbolton, the calculations being 199 and 193 feet. Probably part of the wide spread of gravel near Stockbridge from 180 to 160 feet belongs here, the curve giving 937/180.2.

The next graded reach is too short to allow a curve to be calculated, but below it comes an excellent stretch from 1411 to 1244, over 3 miles, with 17 levels. A range of curves with parameters from 60 to 100 feet fits within .8 ft. and all come nearer to the Mottisfont Terrace of White [8] than to any other known. At Mottisfont, where the edge of the terrace is 112 O.D., the extreme calculations are 112.8 and 100.2. A median curve gives 558/106.2. Extrapolation is 12½ miles.

Below the graded reach the river is entrenched, suggesting a nick, which, south of Stockbridge, develops into a terrace about 10 feet above the river. Three miles below Mottisfont a terrace is crossed by the 100-ft. contour, the curve allowing 445/101.41.

[1] The parameter is the length k in the expression $a - k \log (p - x)$ for the height, where x is the horizontal distance from datum.

Miss Boswell identified the Mottisfont Terrace with the Iver Terrace, and the writer agrees. Near Romsey it maintains a height of about 100 feet for some miles, as does the Iver Terrace of the Solent river between the Avon and Southampton Water.

But between the Mottisfont and the Sleight Terraces lie White's Belbin's Terrace [8], which is a little over 130 feet at Belbin's Farm, near Timsbury. Assuming this to be connected with the graded stretch from 1621 to 1554, a mile and a half, it is easy to fit a curve $y = 397.7 - 85 \log (1750 - x)$, not more than .7 ft. from any of the 11 levels available on this part of the profile. It gives 150.3 at Stockbridge, where are wide flats near 150 O.D.; 149.3 at 900, where the Survey record a terrace 40 feet above the river, here at 109 O.D.; 132.4 at Belbin's; and 129.3 at Romsey, where there is a terrace with spot-level 127. This is certainly the Boyn Hill Terrace and, as usual, Acheulian implements have been found abundantly in its terrace-gravels.

By this scheme of Sleight, Boyn Hill and Iver Terraces every known terrace in the Test graded above 100 O.D. has been accounted for.

The 8 miles below the Iver section of the profile are difficult and better discussed after a lower reach has been identified. From 779, Houghton mill, to 588, Mottisfont bridge, nearly 4 miles, the stream is well graded. This flood-plain is continued for 2 miles by an elevated terrace, which is only 2 miles from a terrace north of Romsey. The curve $y = 150.9 - 33 \log (826 - x)$ is, when allowance has been made for silting at 737 and 675, nowhere more than .7 ft. out, except at Mottisfont bridge, which appears to be affected by a mill-dam and Railway bridge. Measurements above the river carry on to 447/65.6 (see Fig.) where the curve shows 65.8 At 330, north of Romsey, where an extensive terrace has a spot level 59, it shows 61.9. This terrace must be the Staverton Terrace, judging by its position relative to the Taplow Terrace about and south of Romsey.

The writer has mapped the Taplow Terrace of the Solent River to the mouth of Southampton Water, with its lowest edge at 50 O.D. The base of the gravel terrace which runs from Hamble to Netley is close to 50 feet, so the surface level is probably near 60 feet. In Southampton a somewhat higher terrace leads up to a gravel spread near Romsey with a spot level 79. This appears to point to a terrace, half a mile long, at Bossington, 760, along which the 100 ft. contour runs, and thence to a graded reach, which begins just above the Staverton flood-plain and continues up to 978, about 3½ miles. Satisfactory measurements in this reach are less frequent than usual. In the upper half at least 4 water-levels are held up by weirs; in the lower half the river tends to be braided and affected by shallows. The curve $y = 161 - 27 \log$

$(1000 - x)$ fits to .7 ft. and gives 97 feet at Bossington and 85 feet at Romsey.

This leaves unidentified a graded reach between Iver and Taplow, from 1156 to 978, 3½ miles, which can be fitted to .9 ft. by a series of curves with parameters from 50 to 70 feet, e.g., $y = 274.4 - 60 \log (1364 - x)$, apart from an anomaly at 1031, which may be due to silting above Longstock weir. The continuation of these curves is nearer the Iver Terrace than to anything else known, and the reach may perhaps be a second Iver. It will be referred to provisionally as the Longstock reach. The only known terrace in another river to which it might correspond is that at 82 O.D. near Lymington [**9**], which has not been found farther west; but that may be due to inadequate observation. A full explanation of this part of the profile can only be obtained by more complete knowledge of the terraces. Among the hypotheses available, that which seems most likely to the writer is that it is due to a diversion of the river Solent in Iver times from north to south of the Portsdown inlier, the west end of which crosses the Meon in Fig. 1. Bury has indicated the course of the "Goodwood bluff" at the top of the Boyn Hill Terrace between the Avon and Southampton Water [**10**]; its continuation would pass near Netley. The line westward from Goodwood to Funtingdon, east of the inlier, would also pass to the north of it. Spreads of gravel, which seem to be too large to be laid down by the existing streams, lie between Netley and Funtingdon. No trace of the Boyn Hill Terrace is recorded along the north shore of Spithead, and the well-known Portsdown raised beach is at the level appropriate to the Iver, not the Boyn Hill standstill. This is all consistent with the suggested diversion.

It will be noticed that the parameters of the calculated curves increase with the asymptotic distance. This is of course the flattening of a river-course as it lengthens. If the parameters are plotted against the asymptotic distances, they are seen to fall into two groups, with the Longstock reach intermediate. This supports to some extent the interpretation by a diversion.

Three more graded reaches come below the Staverton reach. From Timsbury, 430/59.5 to 361/44.4; from 322/35.9 to 212/28.2; and from 212/28.2 to 103/10.6. The first resembles the "Upper Buried Channel" which extends in the Dorset Stour from about 70 to 50 O.D. In both rivers the gradient is steep and must plunge under the Muscliff Terrace, presumed to be also present in the Test, so that any elevated terrace would be buried. An approximation to the reach is $y = 102.9 - 30 \log (454 - x)$. Measurement 340/42.1 is held up by Sadler's Mill. While the disappearance in the mill-pond of the upper part of the reach below makes the calculated curve tentative, a good fit is $y = 60.9 - 15 \log (368 - x)$ which extrapolates to 22.4 at datum. A mile west of datum an area of alluvium bears three bench-marks between 23.3 and 24.2 O.D., which suggest a terrace near this level. It can only be the Christchurch Terrace [9].

The latest flood-plain mapped in the Stour has a nick at Longham at 34 feet and is known to plunge under a terrace near 10 O.D. The corresponding reach in the Test is from 28.2 to 10.6. As Miss Boswell points out, it is remarkably steep.

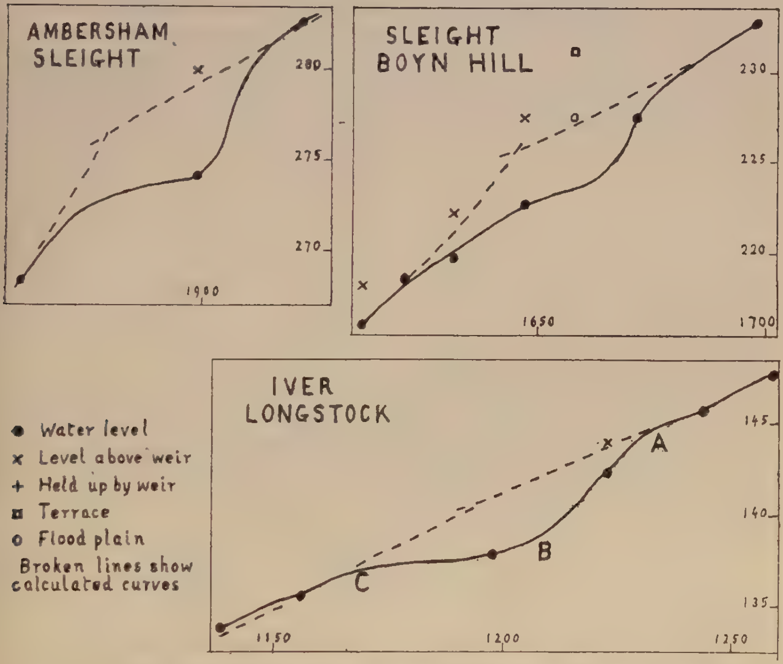

FIG. 17.—THE INTERVALS BETWEEN GRADED REACHES ON THE RIVER TEST.

The intervals between the graded reaches on the Chalk appear to conform to a sigmoid curve, which is best shown by the measurements in Fig. 18, of the Boyn Hill-Iver interval. The other figures have fewer measurements, but they are consistent with such a curve. The Staverton-Upper Buried Channel interval, at the junction of Chalk and Tertiary, is similar, though less regular.

Using Fig. 17 as illustration, the water, moving at A on a graded slope falls down a steep ungraded slope. The velocity and erosive power increase till, at B, both are at a maximum. The water then flows along a very slight ungraded slope until the velocity is checked enough to be that of the next graded reach at C. Maximum erosion being at B, the steep part AB must move upstream. It would be

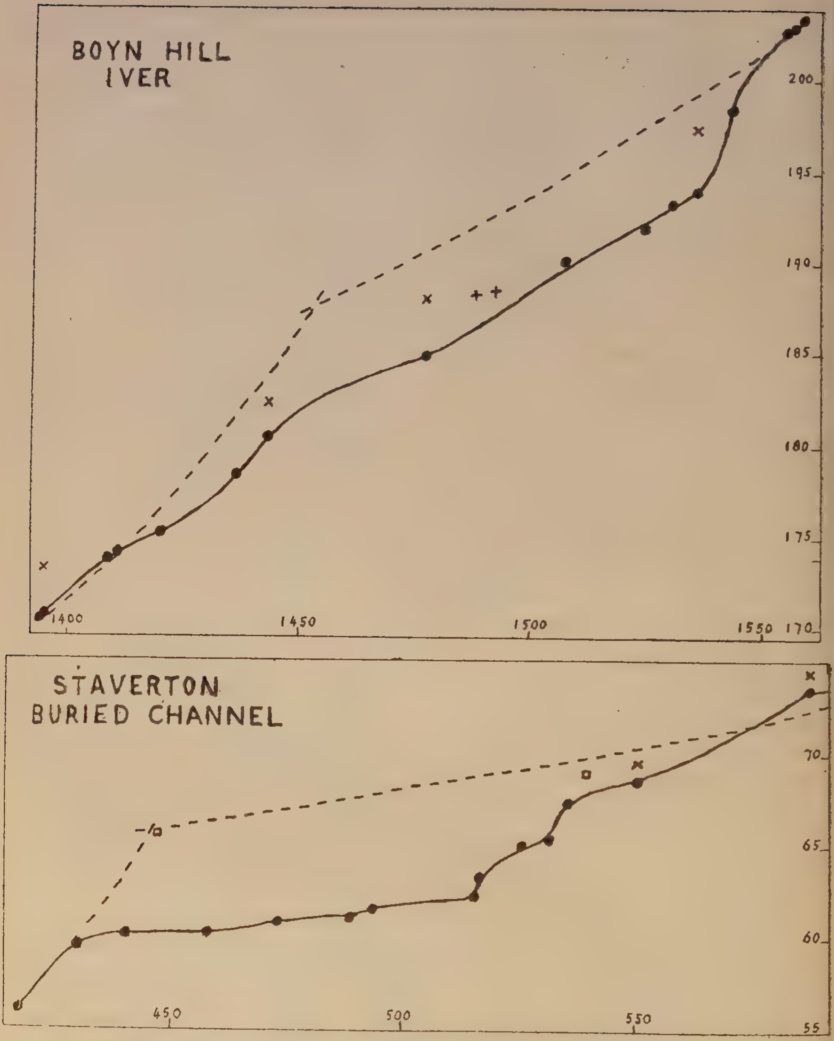

FIG. 18.—THE INTERVALS BETWEEN GRADED REACHES ON THE RIVER TEST.

interesting to ascertain how far water nicks in other rivers are similar in shape. The peculiar terrain of Chalk rivers, with a porous, but resistant, gravel capping a limestone, may have something to do with it. Any small hollow or channel in the flood-plain near a nick is rapidly filled with quickly flowing water, seeping from waterlogged gravel, and it is possible that the gravel is thus cut back more quickly than the underlying chalk. As the channels coalesce they enclose eyots, one of which can be seen in course of formation at the nick at Canford in the Dorset Stour [**9**]. A good example is the gravel "island," figured on p. 72 of the *Winchester Memoir*, at the 100-ft. contour on the Test, which is part of the Taplow flood-plain isolated by the Staverton cut-back. Eyots are often described as shoals, but those which the writer has been able to study turn out to be fragments of terraces.

If now the water nicks are taken at the brow of the plunge which ends each of the graded portions of the stream, they are at the following levels in feet O.D. 282 ; 230 ; 201 ; 144 ; 118 ; 99 ; 68 ; 43 ; 28. (The nicks at 118 and 99 are given by intersection of curves within millponds.)

In each of the ungraded intervals there is a lower secondary water nick. The levels are :—272 ; 219 ; 182 ; 136 ; 60.

All the former are the starting points of elevated terraces. Apparently none of the secondary water nicks connect with terraces, though this requires verification. Miss Boswell's determinations correspond closely to those obtained by analysis of the profile. The only differences of moment are (1) the writer places the nicks between the Boyn Hill and Iver flood-plains somewhat lower than Miss Boswell's 206 and 192 O.D. Fig. 18 shows the difficulties of this section. (2) The writer considers that Miss Boswell's nick at 169 cannot be maintained. (3) He adds an extra nick at 43 O.D. and a secondary nick at 219. The former site is affected by the Muscliff delta and probably also by silting above Sadler's Mill.

In the ungraded intervals temporary flood-plains are formed, which do not conform to the graded flood-plains of the terraces. They do not seem to come within the definition of "flood-plain" by Gilbert [**11**], and must be destroyed as the nicks retreat upstream. Their existence explains anomalies found in the course of determining nicks by measurements on terraces. These land surface nicks would correspond, if the temporary flood-plains are omitted, to the intersection of the calculated curves, which would be lower down the river than the water nicks, but at nearly the same height.

I am grateful to Miss Boswell and Mr. Skeet for giving me the opportunity of studying their interesting observations.

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APPENDIX

Numerical data

Height of nick point K.C.B.	Height of nick point J.F.N.G.	Length of graded reach below nick miles	Curve fitting graded reach $y =$	Correlation of reach
290	282			
263	272	3.7	$451.5-90 \log (1970-x)$	Sleight terrace
238	230			
	219	1.5	$397.7-85 \log (1750-x)$	Boyn Hill terrace
206	201			
192	182	3.4	$344.7-80 \log (1546-x)$	Iver (Upper Taplow) terrace
169				
150	144			
135½	136	4.0	$274.4-60 \log (1364-x)$	? Second Iver terrace
115	118	3.5	$161-27 \log (1000-x)$	Lower Taplow terrace
100	99	3.9	$150.9-33 \log (826-x)$	Staverton terrace
74	68			
60	60	1.5	$102.9-30 \log (454-x)$	Upper Buried Channel flood-plain
	43	2.3	$60.9-15 \log (368-x)$	Christchurch terrace
28	28	2.0	$.165x-6.6$	Stour flood-plain below Longham

The terminals of the graded reaches are taken half-way between measured points on graded and ungraded portions of the river.

AN OUTLINE OF THE GEOLOGY OF ASHOVER, DERBYSHIRE.

By G. S. SWEETING, D.I.C., F.G.S.

[Written for the Easter Field Meeting, 1946.]

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I. INTRODUCTION.

ASHOVER—or "Asher" as it is called locally—is situated just within the southern boundary of the Peak District, about seven miles S.W. of Chesterfield and four miles N.E. of Matlock. Lying secluded in a valley, through which the picturesque and meandering River Amber cuts its way, the village stands at an altitude of about 600 ft. O.D. and is shut in, or framed, by high ridges of Millstone Grit. With winding and narrow streets, houses and cottages built of warm-grey grit, and an imposing church dating from the 11th century, Ashover is a quiet and typical Pennine village. It has about 2,500 inhabitants, whose main occupations are either quarrying or farming.

The seclusion and attractiveness of Ashover is largely due to the fact that it is by-passed by all main traffic, the nearest main road, that from Chesterfield to Matlock, being about a mile to the north-west at Kelstedge.

On the south of the valley stands Overton Hall, which was at one time the home of the naturalist, Sir Joseph Banks (President of the Royal Society from 1778-1820). On the north is Eastwood Hall, left in ruins by Cromwell during the Civil War period, and now overgrown.

The Ashover district contains numerous quarries and other large exposures which serve to make the area particularly interesting both to the petrologist and palaeontologist. Three prominent natural landmarks also occur, known as the Fabric, the Wire Stone and the Turning Stone. They all lie at approximately 1,000 ft. O.D. and consist of Millstone Grit. These features and the conspicuous hill of Ashover Hay form the general boundaries of our traverses during the Field Meeting.

Ashover was at one time the scene of much mining activity, lead and zinc having been extensively worked for many centuries; at the present time fluorspar is being widely reclaimed and exploited from old dumps and workings throughout the district.

The only occasion that the Association appear to have visited Ashover was in 1932, when Professor W. G. Fearnsides, F.R.S., and others conducted the Easter Field Meeting to Bakewell and the valley of the Derbyshire Derwent. During the meeting, one day was devoted to the "Limestone Inliers of Ashover and Crich." For the use of members attending that meeting a detailed and interesting pamphlet was prepared by the Directors, a publication which the present writer has freely consulted and used [8*].

II. PHYSICAL FEATURES.

The Ashover region is essentially an eroded dome with the River Amber forming the major physiographic feature of the district and splitting it into two approximately equal parts. Two small streams which rise on the dip slope of the Millstone Grit about 3½ miles N.W. of Ashover and at about 960 ft. O.D., unite to form the main Amber just above Kelstedge. Flowing in a south-westerly direction the river follows the strike of the rocks and is in the main parallel to the Derwent, about 4½ miles to the south-west. From its source the Amber falls rapidly and leaves the Ashover district at Milltown, just below the 450 ft. contour, finally entering the Derwent at Ambergate seven miles to the south. Its fall is greatest above Kelstedge, just outside our area, and it drops only about 150 ft. within the boundaries of the map (Plate 7).

The head-streams of the Amber take their rise on the open plateau-like escarpment of the grit to the N.W.; but the valleys soon become deeply cut and are sometimes well wooded, as, for example, in Eddlestow Wood ("The Trossachs") west of Kelstedge. Evidences of rejuvenation and its accompanying river terraces are therefore abundant in this part of the Amber, particularly so in the areas consisting of alternating shales and grits above the limestone. West of Ashover, the main terrace feature occurs at about the 600 ft. contour.

The rejuvenation is well seen in the two tributaries above Ashover village. The small stream beginning on the plateau East of Eddlestow Farm is deeply incised in a very narrow valley near the Slack.[1] It descends over 200 ft. in half a mile by a series of small waterfalls over the grit bands. Terraces also occur along the Marsh Brook, which is now cutting its way into the shales.

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* For List of References see p. 135.

[1] Slack—a hollow, especially one in a hillside; a pass between hills.

In the broad shale outcrop, south of Amber House, the valley is more open and the terrace feature rises more slowly from the river. On entering the limestone, the valley becomes somewhat gorge-like, though the band of alluvium is fairly wide and the river meanders considerably, forming ox-bows. The country here is reminiscent, in miniature, of some of the famous Derbyshire dales. Though the sides of the valley are steep and in parts cliff-like, due to the resistance of the limestone to weathering, the river itself is probably an old feature. This may be the result of superimposition from a supposed Triassic cover [**8**, p. 162].

The scenery of the area is mature and a remarkable correlation is apparent between rock character and land form. Almost everywhere the shales form ill-drained flat areas, their altitude being controlled by the base level of the Amber. The grit bands and limestone stand out as the higher areas, particularly the former, which enclose the region at about 1,000 ft. O.D. The limestone-slopes on both sides of the river form gently rolling " dry " country —usually pasture land and much cut up by extensive quarrying operations. This part of the area appears to be relatively unaltered since the shale cover was stripped off.

The grit bands vary considerably in width. On the east they are narrow and ridge-like in character and the steep dip accounts for the close proximity of the Coal Measures at Clay Cross only two miles outside our area. On the west of the valley the bands are much wider and the long dip slope of the Millstone Grit and its associated shales stretches away to the Derwent Valley. It forms a " rolling plateau rather than a characteristic dip slope " [**8**, p. 156], having an elevation of between 800 to 1,000 ft., the highest point being at the Wire Stone (1,038 ft.). These areas are often desolate and featureless, and, occurring on badly-drained watersheds, their boggy and swampy ground renders the discrimination of grit from shale extremely difficult. These flat-topped grit-shale surfaces are presumably due to the long and generally uninterrupted erosion of the Peak District, which has continued since late Carboniferous times.

Landslips are common in the Ashover area, as in many other parts of the Peak District. The type of slipping appears to depend largely upon the amount of dip of the alternating grit-shale series. At Hole Wood in the south, landslips appear in the form of large mounds and hillocks. This arching-up of material may have originated by the weight and pressure of the overlying grits, causing the shales to be squeezed up and to be spread-out or " creep " over the flat slope of the valley. Further, on this movement taking place, the shales would quite likely carry with them a covering of the overlying grit, and an example of this is well seen at Ravensnest. In this connection, it is interesting to note that strong springs arise at the base of the grit; hence, with consequent lubrication of the shales, there would be good opportunity for "sapping" or headward erosion, as witness the cirque-like hollow of Ravensnest.

In the east of the area, where the dips are generally steeper, slipping sometimes occurs in the form of "steps" and this can be seen in progress today on the western slopes of Ashover Hay.

Another type of slipping or sliding—though on a much smaller scale—is commonly seen on the steep grassy limestone-slopes. Here and there the slopes are scored by small *terracettes* or "sheep tracks" in the soil which rarely exceed a few inches in height and result from these miniature landslips.[1]

Another feature of the area is the presence of large detached blocks of Kinderscout Grit, some weighing several tons, which occur perched at all angles on the hill-slopes leading up from the shale hollows to the grit scarps. They are particularly noticeable in the area from the Slack to the Turning Stone. The origin of these blocks is obscure.

With its long geological history and diversity of rock types within so small an area, Ashover shows a wealth of physiographic detail and scenery that varies widely over very short distances.

III. STRATIGRAPHY.

The rocks occurring in the Ashover district include the upper beds of the Carboniferous Limestone (Dibunophyllum sub-zone), Limestone Shales, two members of the Millstone Grit Series (with associated shales), and a volcanic rock contemporaneous with the limestone.

The strata of both the Carboniferous (or Mountain) Limestone and the Millstone Grit in Derbyshire were deposited in comparatively shallow water, and each bed tends to vary laterally over short distances. Such lithological changes and variations in the deposits are well seen in the Ashover district.

The succession is as follows:—

Millstone Grit	Middle Grit (or Chatsworth Grit) Grit Shales Kinderscout Grit Limestone Shales = Butts Shales

Carboniferous Limestone. Upper Dibunophyllum sub-zone
Volcanic Rock (Contemporaneous). Tuff—Toadstone

Carboniferous Limestone.

The Carboniferous Limestone forms part of the Upper Dibunophyllum subzone and has a maximum thickness of about

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[1] C. F. S. Sharpe. *Landslides and Related Phenomena.* 1938, pp. 70-74.

200 ft. Many quarries occur in the district where the limestone can be examined [**4**].

Varying in composition, colour and structure, the rock is light grey, blue, or grey-black in colour, the lighter-coloured beds often being made up of practically pure carbonate of lime ; occasionally, the darker varieties contain small amounts of bitumen and argillaceous material. The bitumen occurs in small cavities in the rock and is present in two forms : (1) as a black hard variety which, when broken, exhibits highly lustrous surfaces ; (2) a very soft, plastic or wax-like variety.

The limestone, as a whole, is generally very hard and tough and has a noticeably hackly fracture, characters that have led to its employment for making tarmacadam roads. In places, silicification and dolomitisation have taken place and this has resulted in the obliteration of all traces of organic remains. On weathering, the rock occasionally assumes brown and ferruginous turreted forms which have probably arisen from the effects of oxidation and dolomitisation.

The upper beds of the limestone are often packed with crinoid stems and *Productus giganteus*. This fossil is particularly abundant and characteristic in the area, some beds, over six inches thick, being made up almost exclusively of the species.

Another feature of the upper part of the limestone is the presence of chert, which occurs as nodules or bands of about six to nine inches thick, traversing the rock over wide distances. In colour, the chert is grey or black and is much brecciated and often conspicuously banded ; it sometimes contains well-preserved silicified fossils, such as productids, corals and crinoid stems—locally called " fossil screws."

Although the origin of Carboniferous Chert is now generally accepted as secondary and represents the replacement by metasomatism of the limestone, it was for many years the subject of much discussion, and various theories as to its formation were advanced. W. Hill [**12**] considered much Carboniferous Chert had originally been an almost pure deposit of sponge spicules, carrying but little calcareous material : it was " obviously not due to the segregation of disseminated silica in a calcareous rock, but practically the remains of sponge beds." H. C. Sargent [**16**] believed the cherts of Derbyshire to have been formed by direct chemical precipitation of inorganic silica held in solution in sea water. P. Jessop [**15**] in 1931 recognised three forms of chert in the Carboniferous Limestone of the northern part of the Peak District : one type contemporaneous with the enclosing limestone and two, secondary, replacing the limestone.

Palaeontology. Having had, for several years, the opportunity of much " general collecting " with Imperial College student field-parties in Ashover, the author here records a list of fossils he has found in the Carboniferous Limestone :—

Productus giganteus (Martin)
  „ *semireticulatus* (Martin)
  „ *latissimus* J. Sowerby
  „ *sulcatus* J. Sowerby
  „ (*Buxtonia*) *scabriculus* (Martin)
  „ *pustulosus* Phillips
  „ cf. *hindi* Muir-Wood
Pugnax sp.
Spirifer striatus (Martin)
  „ *trigonalis* (Martin)
Composita ambigua (Sowerby)
Syringothyris cuspidata (Martin)
Camarotoechia sp.
Schizophoria resupinata (Martin)
Lithostrotion "*basaltiformis*"
  „ *junceum* (Fleming)
Lonsdaleia floriformis (Martin)
Zaphrentis spp.
Dibunophyllum spp.
Aulophyllum fungites (Fleming)
Clisiophyllum sp.
Cyathaxonia rushiana Vaughan
Syringopora spp.
Rhodophyllum sp.
? *Euomphalus* sp.
Crinoids
Bryozoa

The following are the quarries from which the above have been obtained :—

Butts Quarry, about half a mile west of Ashover Church on the south side of the Amber, opened up in 1926, previous to which it was only a small working. Situated at the extreme boundary of the outcrop, the limestone is well-bedded and blue to blue-grey in colour. This quarry is one of the largest in the area and has a working-face varying in height from 80 to 100 ft. It is not shown on the present 6-inch Ordnance Survey map.

Hockley Quarry,[1] situated at the upper end of the Ashover-Milltown Road, just outside the village and south of the Church. This quarry shows a 75 ft. vertical face and is almost a true strike section ; the upper part is thinly bedded and in it five continuous bands of chert occur ; the lower portion of the quarry is massive

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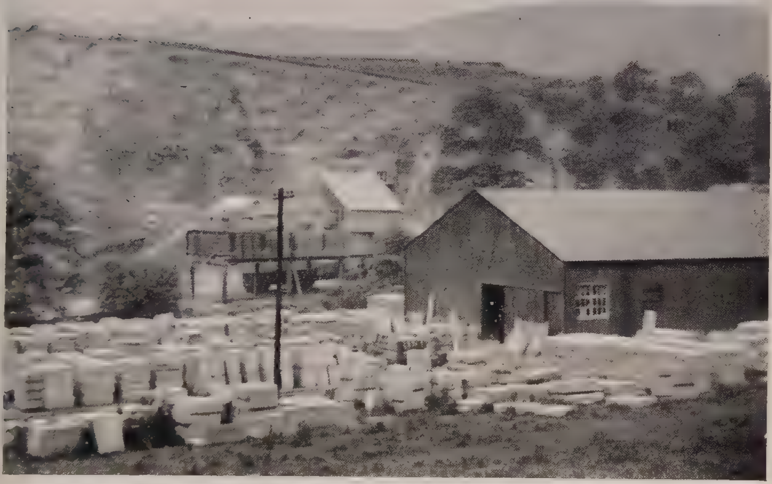
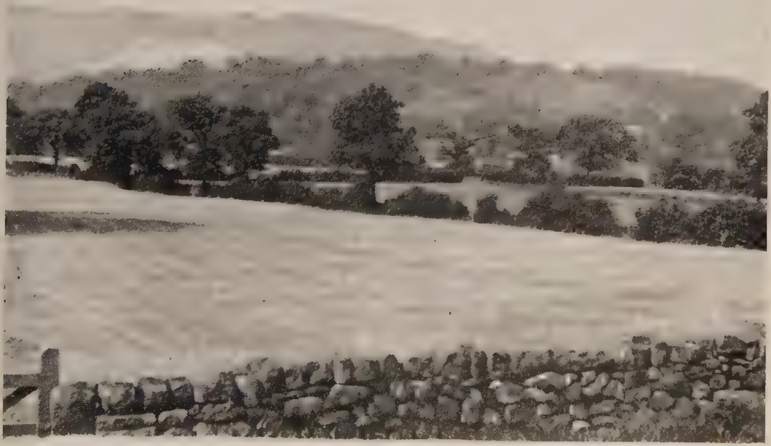
[1] Hockley Quarry now serves as a private quarry-garden belonging to Dr. Gerald Fine of Hockley House.



A. BUTTS QUARRY, ASHOVER.



B. CARBONIFEROUS LIMESTONE INLIER WITH MILLSTONE GRIT RIDGE ; From Milltown, looking west.

[*To face p.* 122.

and well jointed. The full thickness of the limestone, which in one place rests on the toadstone, is estimated to be 135 ft.

Cockerspring Wood. Old quarry-workings occur in the wood near to and N.E. of Overton Hall. In the largest of these, an excellent dip and strike section can be seen with about 10-12 ft. of limestone, the upper portion rubbly and thinly bedded, the lower massive. In the upper part a bed about 9 in. thick is made up almost entirely of *Productus giganteus.*

Overton Hall. Excavations in the limestone just east of the Hall have recently been opened up for fluorspar. The rock is a well-bedded blue-hearted limestone and has proved to be very fossiliferous.

Butts Shales.

For many years there was controversy regarding the age of the shales which succeed the massive Carboniferous Limestone. In 1923, however, J. W. Jackson [**13**] identified in them certain goniatites from a number of localities in the Edale Valley and subsequently classed the beds with the Millstone Grit Series, giving them the name " Edale Shales."[1]

As the best exposure of these shales in the Ashover district occurs at Butts, it is proposed to adopt a local stratigraphic name for the purpose of this Field Meeting Pamphlet and refer to them as the " Butts Shales."

The Butts Shales are nearly always jet black in colour, but in rare cases they are fawn coloured and biscuit-like in character. Thin seams of earthy limestone often occur inter-bedded in the shales and pyrite is also present, which, on oxidation, gives rise to reddish-brown streaks or bands traversing the beds. In the stream bed, Bullions[2] are common, as at Butts, but so far they have not been observed in the shale itself. When split open, the bullions often contain " solid " goniatites.

The Butts Shales are well exposed in the banks of the road on the western flank of Ashover Hay, and also in the Ravensnest area east of the Gregory Lode. The best and largest exposure (as previously mentioned) is at Butts itself, where in the banks of the Marsh Brook—just below B.M.592.4—a section varying from 10 to 12 ft. thick can be examined.

Higher up the brook, above Marshgreen House, other good sections are seen. Here, however, the shales are often pale brown or fawn coloured and coarser in texture.

There is little, if any, opportunity of arriving at a satisfactory estimate of the thickness of these shales, but some indication of their approximate thickness is given by the old engine shaft on the Gregory Lode (near Milltown), where about 400 ft. of shale was penetrated before the limestone was reached [**9**, p. 26].

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[1] In a later paper, 1927 [**14**], Jackson showed the distribution of the fossil bands in the shale deposit of Edale and Mam Tor.

[2] Calcareous, siliceous or ferruginous nodules ; also sometimes found in the roof of coal seams.

The sudden lithological change from a shelly limestone to black shale—which moreover occurs at varying stratigraphical levels—is a point of much interest. In this connection, Professor Fearnsides [**8**, pp. 175-176] has made some interesting observations and suggestions regarding these abrupt changes of deposition. He writes :—

> ". . . . one can hardly explain it except by regional further submersion of both the shell-reef and the margins of the land area to the south. The fine-grained sediment must have come as siftings of land waste settled out beyond the edge of the south-westward-advancing delta of the river which later made the sandbanks of Shale Grit, and thereafter the coarser members of the Millstone Grit and Coal Measures. The chemical composition of the top limestone beds of the Lower Carboniferous contrasts so strongly with that of the Edale Shales, that, in the absence of a junction conglomerate, change of chemical conditions is sufficient to explain the corrosion and discordance where the two formations join. Chert in the limestone, and phosphate and bitumen in the shales, and the discovery of concretionary nodules of chlorite containing radiolaria, are more suggestive of a submarine non-sequence than of a sub-aerial erosion or a wave-cut shore-line break."

As in other parts of North Derbyshire, the shale in the Ashover district appears to rest on an irregular surface of the underlying limestone. Hitherto, the lowest goniatite found in the district was of Millstone Grit (R_1) age [Bisat, **8**, p. 178], from which it would appear that an important non-sequence separates shales and limestone. Recently, however, collections of fossils from the Marsh Brook made at different times by Dr. Alan Wood and the writer have been submitted to Dr. C. J. Stubblefield, F.R.S., and Mr. W. S. Bisat for identification, and it appears that the character of the contact between limestone and shale needs re-investigation. The fossils found included :—

Fauna A (Dr. Alan Wood). From fawn blotchy shales.

Chonetes cf. *laguessianus* de Koninck ; *C.* cf. *longispinus* F. A. Roemer ; and *C.* (*Plicochonetes*) sp.
Crurithyris sp.
Productus (*Plicatifera*) sp.
Posidonia sp.
Pseudamusium sp.
Goniatites sp. with crenulate ornament.
Phillibole cf. *aprathensis* R. & E. Richter, pygidium.
P. cf. *culmica* R. & E. Richter, pygidium.
P. cf. *laticaudata* (Sarres), free cheek.

The trilobites are characteristic of P strata in Rhineland, and the goniatite fragments confirm this P (Lower Carboniferous) age.

Fauna B (G.S.S.). From black shales, in which the fossils are smeared :—

Reticuloceras of *R. umbilicatum* Bisat & Hudson group.
Dunbarella [*Pterinopecten*] sp.
Plant fragments.

At this locality a second faunule occurs, in which the fossils are preserved as clearly-defined casts and moulds, and mainly comprise *Dunbarella* [*Pterinopecten*] sp.

These fossils are indicative of Millstone Grit (R_1) age.

Fauna A was collected at the point indicated on the map (Pl. 7) by the eastern dip-arrow, a quarter of a mile north-west of Butts, and Fauna B was collected only 30 yards to the west, at the position of the second dip-arrow. The two exposures are nearly on the same strike line, and there is certainly not room for intervening strata of E and H age between them. The interesting point arises that the shale sedimentation had already begun in this district in Lower Carboniferous times. Therefore, either a non-sequence occurs in the shale series itself, or an important fault has cut out the E and H zones in this section.[1]

In this connection it is of interest to note that faulting probably does occur only about half a mile N.W. of the limits of our area. Recently (September, 1945), while mapping beyond Kelstedge, Dr. G. W. Himus and the author found Middle Grit in apparent contact with Kinderscout Grit. In the old quarry at Brockhurst, Middle Grit dips at 24° S.30 W., while in the Smalley Brook less than 200 yards due west, the upper beds of the Kinderscout Grit crop out on the steep westerly banks of the stream, with no evidence of the Grit Shales.

The fault, if such, appears to have a south-easterly trend, and the brook, for at least part of its course, apparently runs along the line of the disturbance. It is possible, therefore, this fault may prove to pass at some point into the Butts Shales themselves. From further mapping which is being carried out in the Brockhurst area, it is hoped that more definite information will become available.

Kinderscout Grit.

Forming bold, cliff-like escarpments and prominent hills, the Kinderscout Grit is a hard, massive, micaceous rock having a texture ranging from fine-grained to coarse, conglomeratic, or pebbly. The upper part of the formation is thinly bedded with occasional limonitic concretionary nodules. The lower part is massively bedded and exhibits markedly smooth and clean rock surfaces. Between the thickly-bedded material, thin siliceous shaly bands (about 1-2 in. thick) often occur. Differential weathering, current bedding, ripple marking and prominent jointing are characteristic features of the rock, which in the Ashover district is estimated to be from 325-350 ft. thick.

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[1] It is hoped to investigate this matter and to collect more material from the Marshbrook stream during the field meeting.

The grit also gives rise to two conspicuous landmarks, consisting of isolated crags which are possibly the relics of older land surfaces. These are known as the Turning Stone (1,000 ft.) and the Fabric (982 ft.); they both show the varied lithological characters common to the Kinderscout Grit as a whole.

Along the escarpment, west and south of Ashover, large quarries occur, viz.: Ambervale, Dutton, Bradley, and Cocking Tor. There are two quarries at Cocking Tor, one now long disused and the other adjoining it, known as the Robin Quarry. All these quarries show excellent sections, 50-75 ft. thick, the upper part often thinly bedded with nodular material and containing shaly bands; the lower portion is fine-grained, compact, clean and thickly bedded. At the Robin Quarry, prior to 1940, a face of about 80 ft. was exposed, the beds varying from 4 ft. to nearly 20 ft. thick with wide, open joints. (See p. 134.)

On the east of Ashover, the Grit is also well exposed on the narrow scarp-slopes running from Fabric Wood in the north to Knotcross Farm on Ashover Hay in the south.

Other than small indeterminate fragments of brachiopod or lamellibranch shells, with occasional plant remains, no fossils have been found by the writer in the Kinderscout Grit of the Ashover district.

Grit Shales.

This series consists of blue-black shales with thin silty bands and small nodules of ironstone. The prevalence of ironstone can be seen in the ditches and drainage channels cut near Jockey Farm (S.W. of Ashover), where the shales are in places deep brownish-red in colour and paste-like in character, resembling bog-iron ore. They form flat, boggy, marshland which, despite long and persistent efforts by farmers, has proved practically useless for cultivation or grazing purposes. In thickness the series may reach about 150 ft. No fossils have been found by the writer in these shales.

Middle Grit (Chatsworth Grit).

Like the Kinderscout Grit, the Middle Grit of the Ashover district is very variable in texture. It is, however, more micaceous and ferruginous. The lower beds are usually very fine-grained and unlike the Kinderscout, in that they are not so massively bedded or compact. The rock is often heavily impregnated with iron oxide, which gives it a pronounced brown or red colouration. It contains many concretions, is often very rubbly and breaks down readily.

Topographically, the Middle Grit, though giving rise to minor ridge-like features and forming the solitary and isolated Wire

Stone outcrop, is far less conspicuous than the Kinderscout Grit, which makes bold features on the landscape.

There are two quarries in this grit, both on the western limb of the anticline : one in the north of the area near Eddlestow, and the other in the south at Poorlots Quarries. Both show similar types of rock—thinly-bedded, micaceous, rubbly and very ferruginous. Except for some workings at the western end of Poorlots, where the grit is less ferruginous and more evenly bedded, the quarries are in a derelict state and have been abandoned for many years.

Toadstone.

For nearly two centuries the igneous rocks of Derbyshire have been the subject of great interest to the geologist and—for an even longer period—a source of much concern to the miner. These rocks, which consist of a series of lava-flows and tuffs, are locally known as Toadstones, a word which was introduced about 1775. It is derived either from the supposed resemblance to the back of a toad or from the German *Todstein* (Deadstone), since it contains little or no metalliferous ore. As much has been written on the Derbyshire toadstones, a brief historical summary is here given on these rocks.

The earliest references to toadstones appear to have been made by Hutton in 1775[1] and by Whitehurst in 1778[2], who considered them to be intrusive into the limestone, but not contemporaneous with it.

In 1811, Farey [7] gave the first detailed account of these rocks and assumed that they were continuous over the whole area.

Conybeare (1822) [**6**, p. 448], in an account of the Trap Rocks of Derbyshire, states that there are three toadstones, the average thickness of the first, or upper, being 60 ft. and the two lower 75 ft. each ; the prevailing structure is massive, a laminated structure being rarely seen. Conybeare also gave a mineralogical description of the rocks.

The conclusion that these igneous rocks had been intruded amongst the limestone was, up to this time, generally accepted, but in 1851 De la Beche[3] proved that the toadstones were interbedded submarine lavas, though whether any of them represented contemporaneous intrusions or ejected ashes or lapilli he was unable to say.

Again, the generally accepted view that the various beds of toadstones were continuous, and could be correlated, in different parts of Derbyshire was beginning to be doubted. For instance, we note that in 1869 A. H. Green [**10**, p. 137] was of opinion that the rocks would be found to be very irregular in their occurrence, and sections "seem to show that, perhaps with one exception, toadstones are found at different spots on very different horizons, and are of limited range."

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[1] *Trans. Roy. Soc. Edin.*, vol. i, p. 275 *et seq.*, espec. p. 277.

[2] *An inquiry into the original state and formation of the earth* (1778), p. 149 *et seq.*

[3] *Geological Observer*, 1851, pp. 642-645.

In 1894 and 1907, Bemrose [1, 3] gave detailed accounts of the field occurrence and full petrographical descriptions of the toadstones. He showed that they could be divided into two groups: (1) those contemporaneous with the Carboniferous Limestone and Limestone Shales, consisting of volcanic lavas and tuffs; (2) others which were intruded at a later period, consisting generally of ophitic dolerites passing by stages into fine-grained dolerites or basalts.

Bemrose also showed that there are three main areas of volcanic activity: the North-Western or Miller's Dale area, the South-Eastern or Matlock area, and the South-Western or Tissington area. In all these districts lava-flows, bedded tuffs and volcanic vents are found, while, in addition, intrusive sills occur in the Miller's Dale and Matlock areas. In the northern part of Derbyshire (Castleton and Miller's Dale) he recognised two widespread series of flows which he termed the Upper and Lower Lavas and which lie 500 ft. and 750 ft. respectively below the top of the Carboniferous Limestone. These lava-flows now prove of much stratigraphical value.

Recently (1939) F. G. Traill [17] dealt with the occurrence of toadstones at Mill Close Mine (about 5½ miles W. of Ashover), and gave particular attention to the lower group. He also made reference to evidence in the limestone of rhythmic sedimentation and its possible connection with the emplacement of the toadstones.

In the Ashover district itself some excellent exposures of interbedded tuffs can be examined. They are considered by C. B. Wedd [9] to be at the same horizon as the Upper Lava occurring at Matlock; it is unlikely, however, that they are in any way connected with this lava. No tuff has been found accompanying the Matlock igneous rocks, and it may be, therefore, that the Ashover Tuff itself has originated from a neighbouring vent, which still awaits discovery.

The chief exposures of the tuff occur in Hockley and Fall Hill quarries, in Salter Lane, along the "Drive" below Cockerspring Wood, and in the bank below Butts Cafe. About 2 ft. of tuff has also recently been exposed in the floor of Butts Quarry at its southern face.

It is at Hockley Quarry, however, that the finest exposure of the toadstone can be seen. In a small cutting leading into the quarry, at B.M.523.3, a section about 30 ft. thick shows 14 ft. of volcanic tuff in contact with, and covered conformably by, Carboniferous Limestone [2, p. 202]. The tuff is dark green in colour, well laminated, and contains fragments of limestone and chert, together with lapilli of the size and shape of a pea or bean. Near its contact with the limestone, the tuff is comminuted and crumbly, but it quickly passes into well-laminated beds. Traversing it are thin stringers or veins of fibrous calcite which extend from the junction of the two rocks to the floor of the quarry. It is interesting to note that as early as 1822 Conybeare and Phillips refer to this exposure, and remark : " The Upper toadstone exhibits in Hockley lime quarry, south of Ashover, portions of limestone embedded in its mass " [6]. A similar, though smaller, exposure is seen by the side of the limekiln at the Fall Hill quarries (near B.M. 515.3).

Of the other outcrops of toadstone, those occurring in the " Drive " are of chief interest. At the entrance to the Drive, close to Demonsdale Farm, a cutting in the bank shows the uppermost part of this rock in contact with rubbly limestone.

The toadstones give rise to a soil which is conspicuously mauve or purple in colour, a feature which is very useful when mapping, particularly so when the rock occurs alongside alluvium. On rare occasions, as at Butts Quarry, where it is much altered and decomposed, the tuff is bright green in colour, very soft, and clay-like in texture.

The full thickness of these rocks in the Ashover district is not known. The greatest thickness so far recorded was at Fall Hill Quarry (mentioned above), where a shaft was sunk to a depth of 210 ft., all in toadstone.

IV. GEOLOGICAL STRUCTURE.

The structure of the Ashover district is comparatively simple. It consists of a denuded elongated dome and forms part of a long and well-defined anticline which extends for about 14 miles in a southerly direction from above Uppertown (two miles N.W. of Ashover) through Ashover and Crich to Belper (Fig. 19).

The axis of the Ashover dome runs N.W.-S.E. and is parallel to the main axis of folding of the Carboniferous Limestone of the High Peak area. The dome is separated from the main limestone massif by the broad band of Millstone Grit forming the eastern edge of the Derwent Valley, which can be well seen at Matlock, four miles S.W. of Ashover.

The Ashover area itself shows no definite faulting, though there is undoubted evidence of movement in some places. The nearest known faults lie just outside our area, south of Ashover Hay ; in fact, the Ashover-Crich[1] anticline is nowhere interrupted by faulting of any magnitude.

In the core of the anticline are exposed the Carboniferous Limestone and its associated toadstone. These rocks form a well-defined pear-shaped inlier which is about one and a quarter miles long and two-thirds of a mile wide at its maximum point.

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[1] Crich, about 5½ miles south of Ashover, forms a conspicuous limestone hill. The outcrop of the Carboniferous Limestone is faulted, and is about a mile and a half long ; the toadstone, however, does not reach the surface.

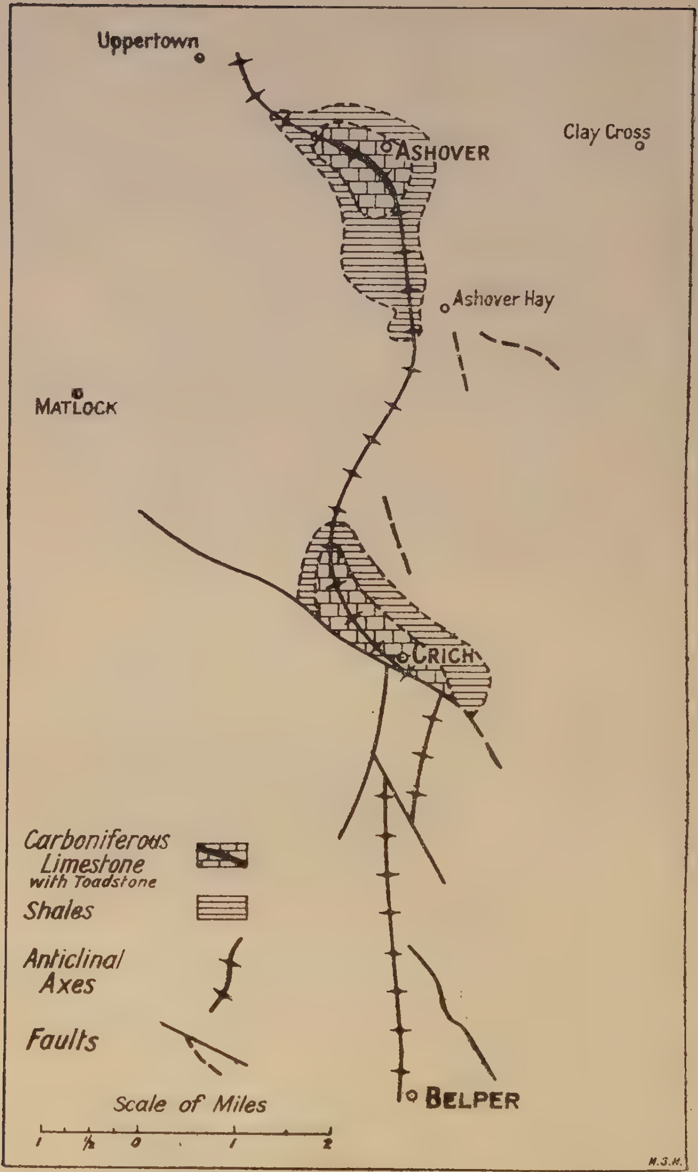

FIG. 19.—SKETCH MAP SHOWING THE ASHOVER-CRICH INLIERS IN RELATION TO THE UPPERTOWN—BELPER ANTICLINE (*after C. B. Wedd*).

The toadstone outcrop is lens-shaped, and has a maximum width of about 220 yards near Salter Lane. It traverses almost the whole length of the inlier and has the effect of dividing the outcrop of the limestone into two equal parts.

The Butts Shales have their widest outcrop on the north and south of the inlier, while, on the west, they attain their highest point in the area. From the footpath near Butts Quarry (at the 600 ft. contour) the shales "mount" the hillslope to Ambervale Quarry at 800 ft., and below Dutton's Quarry, about a quarter of a mile S.S.E., they occur at a height of 900 ft. O.D.

Rising steadily away from the shales and limestone, on both sides of the valley, are bold escarpments and ridges of Kinderscout Grit and Middle Grit, which form a frame-work to these older rocks. The north and south closures of the "frame" lie about two miles and three-quarters of a mile respectively beyond the boundaries of our area. The *width* of the frame, however, varies considerably. On the eastern limb of the anticline the grits dip steeply from 30°-50° and crop out mainly as narrow and sinuous bands with an average width of only about 100 yards, and separated from each other by equally narrow depressions or hollows of grit shales. On the western limb, however, where the maximum dips are only about 15°-20°, the grit outcrops are in some places over 1,000 yards wide, the intervening shales here being responsible for flat and boggy areas.

Evidence of definite movement (referred to above) is seen in the limestone quarry at Fall Hill, near Milltown. At the west entrance to the quarry large vertical slickensides occur which are highly polished and grooved ; they run approximately in the direction of strike of the limestone. The bedding of the rock is very poor and indefinite, jointing is well-marked, and with the exception of a small area at the eastern end of the quarry, where the limestone dips at 21° S.E., the whole rock-face is seen to be much sheared and disturbed.

This leads us to the consideration of some possible related features 200-300 yards south of Fall Hill.

It will be noticed that the Amber flows along the axis of the anticline until it reaches the end of Fall Hill Quarry, where it suddenly turns due south for about 500 yards, following the edge of the limestone outcrop. Instead, however, of cutting its way into the Butts Shales, as might be anticipated, the river makes an almost right-angled bend and crosses the Kinderscout and Middle Grits at, and near, Sheepwash Lane. From here the Amber continues its general south-easterly course to the limits of our area. In addition, the outcrops of both grits from north of Littlemore, have a general N.S. trend until, near the Greyhound Inn, they swing off to the S.W., cross the river and finally resume their normal southerly course.

These somewhat unusual features, together with the disturbed condition of the rocks at Fall Hill near by, suggest the presence of a N.N.W.-S.S.E. fault. Unfortunately, however, no surface evidence is available in the form of a shift or break in the outcrops of either the limestone or grits. Moreover, the Kinderscout and Middle grits in the vicinity of the Amber are very poorly exposed. Descending rapidly from the Greyhound Inn, the ground is undulating, consisting of bluffs and depressions with no certain indication of the position of the beds. Some carefully selected pits or excavations in this area may therefore be needed before a final conclusion is reached on this matter.

V. ECONOMIC GEOLOGY.

No account of the geology of a Derbyshire area would be complete without some reference to its mineral wealth. The most important metal found in the county is, of course, lead, which has been worked intermittently from Roman times. In the same way as we couple "Tin with Cornwall," so one links "Lead with Derbyshire."

The output of lead reached its culminating point in the latter part of the 18th century; during the years 1776-1786 it is stated that Ashover alone produced 2,016 tons annually.[1] Since that time, however, a steady decline in output has taken place, until today there are actually no active mines left in the county. The last mine to cease working was Mill Close, which closed down in 1940. The decline of lead mining in Derbyshire, however, is by no means due to the exhaustion of its mines, but is primarily the result of competition from abroad, which has led to a consequent heavy fall in the price of the metal.

In Ashover, like other districts in Derbyshire, lead is almost entirely confined to the upper part of the Carboniferous Limestone; that is, it is practically restricted to the beds above the toadstone. On rare occasions, however, small fissures in the toadstone have been found containing mineral ores. Bemrose writes: "Though a mineral vein is often cut off by the toadstone, there are some undoubted cases in which the lead-ore has been worked in that rock" [**1**, p. 604].

In the Ashover district there are several mineral veins, the chief of which are the Gregory, Overton, Fall Hill (or Milltown), and the Westedge lodes; the workings all occur above the toadstone. The lead is found in vertical fissures known as "rakes," or in narrow fissures or cracks known as "scrins."

The Gregory Lode runs nearly east and west. It was opened up about a quarter of a mile west of Gin Lane and runs under the escarpment of the Kinderscout Grit to the New Engine Shaft, about 400 yards north of Holestone Farm. From here it turns S. 75° W. from the shaft for about 400 yards, where the mine was abandoned in 1803 [**11**, p. 152].

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[1] Pilkington, J. *A View of the present state of Derbyshire.* 1789.

About 500 yards east of the New Engine Shaft, the Gregory Lode is joined by the Overton Vein. At this point, production was said to be very great and, according to Pilkington[1], from 1758-1783 an average production of 1,511 tons was obtained.

At the Fall Hill (or Milltown) Vein, a shaft was sunk to a depth of 270 ft. reaching the toadstone, and the vein was worked in the Milltown (Spencer) Mine until 1856 [**11**, p. 154].

The Westedge Vein runs about S. 75° E. and closely follows the Butts Shales-Limestone boundary. There are three old shafts on this vein about 300 yards west of the Marshbrook, and at one of them—the most westerly—attempts are now being made (September, 1945) by the Clay Cross Company Ltd. to re-open and work the mine. The depth of the shaft is about 220 ft. and pumping is now proceeding, water being met at 79 ft. Thin earthy limestone bands and yellow ochreous seams have been noticed in the shaft.

All these lodes contain, in addition to galena, varying quantities of zinc blende (sphalerite). Associated with these metals are the gangue minerals—calcite, barytes and fluorspar ; it is remarkable that quartz is almost completely absent from the mineral veins of Derbyshire.

Fluorspar. Of the three gangue materials, fluorspar is by far the most important, though up to comparatively recent times it was the " Cinderella " of all the Derbyshire minerals. It was not until 1899 that the importance and value of fluorspar were realised. Hitherto, the mineral had been looked upon as a practically worthless by-product and was consequently dumped and almost entirely disregarded. From the beginning of the present century, however, fluorspar has found a ready market as a flux in steel-making at Sheffield and elsewhere, and for the manufacture of hydrofluoric acid ; it is also largely used in the ceramic industry.

The price of fluorspar has accordingly risen considerably, and at the present time (1945) it is said to have reached £5 to £10 per ton, according to quality. In 1887, on the other hand, working at the Gregory Lode was " confined to washing the old hillocks for fluorspar, which fetches about 8/- a ton delivered at Stretton Station " [**11**, p. 153].

At Ashover—like its near neighbour, Crich—fluorspar occurs in profitable quantities. It is associated with lead in the lodes at Gregory, Overton, Fall Hill and Westedge. In quarries, as at Fall Hill, fluorspar commonly occurs coating joint planes, slickensided surfaces, and also in small pockets or crevices in the limestone.

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[1] Op. cit., p. 128.

But it is not from quarries only that fluorspar is sought. On the contrary, the search for " spar " is now largely confined to old surface workings, dumps, tip heaps, etc., which have accrued from the discarded and rejected material left by early lead miners. It is this material which is now being carefully sifted and turned over and over for its yield of fluorspar. Thus, scarred hillocks and shallow pits or trenches are familiar and common features of the limestone country of Ashover.

Barytes. Barytes (also known as Caulk) has been obtained from a small vein in an old limestone quarry in Butts Lane. The mineral is cream to white in colour, but often has a pinkish tinge due to iron oxide. The limestone is rubbly and poorly bedded, and occasional slickensides occur coated with barytes. Small tunnels have been driven for a few yards into the north end of the quarry, but since 1942 work has been suspended. Barytes also occurs in the Butts Limestone Quarry. Here the mineral is found, with much ferruginous material, in ramifying, fern- or coral-like growths.

The economic products of Ashover are not, however, restricted to its lead-zinc veins and associated gangue minerals ; the rocks themselves have been, and still are, important contributors. The Carboniferous Limestone is much used as a road metal, for railway ballast, and for concrete aggregates. The Middle Grit from Poorlots Quarry is used as a building stone and for the preparation of grindstones, while the Kinderscout Grit is particularly suitable for the manufacture of pulpstones, some of the finest in Derbyshire, it is said, having been produced from the Ashover quarries.

The grit at Robin Quarry (Cocking Tor) is white to cream in colour, well jointed, massively bedded and extremely well graded. Of all the Kinderscout Grit quarries in Ashover, this probably yields the finest stone and, moreover, is the most easily worked ; huge, massive and flawless blocks weighing many tons are commonly " pulled out " after blasting from the middle beds of the quarry. One of the largest blocks of this type, seen in 1945, was said to weigh over 60 tons. Three types of grit are recognised for the preparation of pulpstones, viz. *Fine*, used for grinding wood pulp in the making of good quality thin paper ; *Medium*, for brown paper and thin card ; *Coarse*, for cardboard and fibreboards for ceilings, etc. The weight of the completed stones varies from about two to over seven tons, the largest (now in the quarry yard) being 5 ft. 7 in. in diameter, 4 ft. 9 in. thick, and 7½ tons in weight.[1]

Shortly before the war new and expensive electrically-driven plant was installed at the Robin Quarry for the manufacture of large numbers of pulpstones, nearly all of which were exported to Scandinavia. But, in 1940, on the invasion of Norway by Germany, trade with the Scandinavian countries at once ceased, and this as a natural consequence resulted in a speedy and abrupt end to all activities at the quarry. Today, tragic evidence of this break can be seen in the form of derelict and abandoned modern cutting plant, and in the completed pulpstones of all sizes left lying alongside sheds, some packed in wooden casings, addressed, and awaiting transport to Oslo and other Scandinavian areas.

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[1] I am indebted to Mr. A. Fletcher, Owner-Manager of Robin Quarry for the information given above.

ACKNOWLEDGMENTS.

The author is much indebted to Dr. C. J. Stubblefield, F.R.S., for kindly identifying the fossils from the Butts Shales ; to Dr. Alan Wood for reading the MS. and for advice, particularly with the palaeontology of the area, and to Dr. G. W. Himus for enthusiastic help and assistance in the field. He also wishes to thank his daughter, Miss M. M. Sweeting, M.A., for valuable help in writing the section on physiography.

Finally, the author takes this opportunity of tendering his best thanks to Brig.-General G. M. Jackson, T.D., J.P., of Clay Cross Company Ltd., and also to the many farmers in and around Ashover, all of whom for many years have willingly given him and Imperial College parties every facility and permission to enter their quarries and land.

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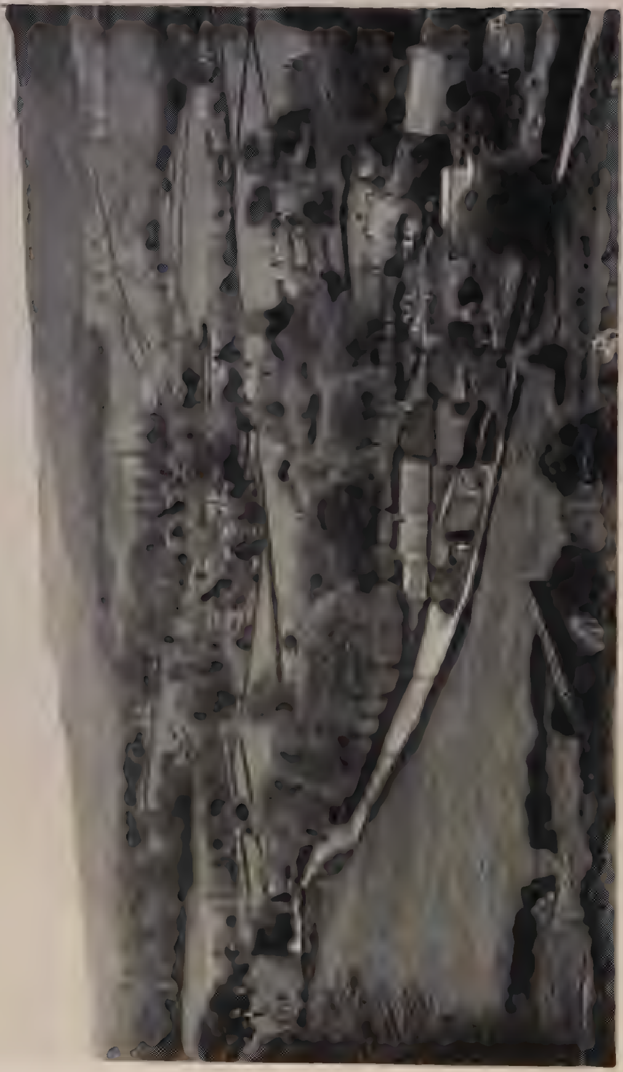
Note.—Since this paper was written R. G. S. Hudson and G. Cotton* have published a detailed account of the Edale Shales (= Butts Shales) of the Edale Anticline, where these beds have a total thickness of about 900 ft. Just south of Edale, in the vicinity of Mam Tor, they record a rapid overlap ; here "the lower half of the succession including all E_1 and the lower part of E_2 are overlapped out" and "this takes place fairly rapidly immediately north of the limestone massif." In the Castleton area the succession of the Visean is incomplete, since upper P_1 and P_2 are missing. This is said to be indicative of erosion and uplift in P_1 and P_2 times, now usually termed the Sudetian crustal movement.

EXPLANATION OF PLATE 6.

A. Butts Quarry, Ashover. Carboniferous Limestone ; in foreground are pre-cast blocks prepared from limestone aggregates. The Kinderscout Grit escarpment is seen behind the quarry.

B. View taken from Milltown, looking west. Butts Shales in foreground, Carboniferous Limestone dome and inlier (wooded area in centre). Kinderscout Grit on sky-line. The light-coloured area on left of photo consists of old mine tips, the site of the Gregory Lode.

***Quart. Journ. Geol. Soc*, 1945, vol. ci, pp. 1-36 ; *see also* J. Shirley and E. L. Horsfield, *ibid.* 1940, vol. xcvi, p. 271.



[C. J. B.

GENERAL VIEW OF ASHOVER.

[*Frontispiece.*

EASTER FIELD MEETING, 1946

ASHOVER DISTRICT, DERBYSHIRE

Report by G. S. Sweeting, D.I.C., F.G.S., and G. W. Himus, Ph.D., F.G.S.

INTRODUCTION

THIS, the first long field meeting since the cessation of hostilities, was well attended. In spite of the inconveniences of travelling and the difficulty of obtaining accommodation, it was found possible to house twenty-seven members and friends in and around Ashover, while six or eight others joined the party daily, coming from Matlock and Derby. On Easter Monday, we were happy to welcome five members from the North-East Lancashire Group of the Association, who showed their enthusiasm by setting out at 6.30 a.m. to join the party at Ashover by 9.30.

In such a small village as Ashover, it was not possible to accommodate twenty-seven persons in one or even in two groups. Members were, therefore, scattered among farms and cottages over a fairly wide area. Careful preliminary work had secured satisfactory quarters, and in spite of the fact that few members had beds to themselves, general appreciation of the accommodation was expressed.

The weather throughout the meeting was good ; there was only one slight shower, and from time to time there was bright sunshine.

Thursday, 18th April

Twenty-nine members of the party, including six who had come over from Matlock, met at 8 p.m. in the Parish Hall, Ashover, where they were joined by Mr. A. Fletcher, of Robin Tor Quarry, and Mr. G. Townrow, from the Butts Quarry. Dr. A. J. Bull, acting on behalf of the President (Mr. C. E. N. Bromehead), welcomed the members and guests, saying how sorry he was that Brigadier-General Jackson, of the Clay Cross Co. Ltd., had been prevented by illness from being present. Dr. Bull then formally introduced the Director, who gave a brief outline of the geology of the Ashover district and, with the aid of marked maps, pointed out the routes to be followed each day. A short discussion followed, and the meeting broke up at about 8.45.

Friday, 19th April

THE KINDERSCOUT GRIT AND MIDDLE GRIT COUNTRY

The first day's traverse was made over high ground in order to see and demonstrate the main structural features of the area.

Leaving the Square, Ashover, about 9.40 a.m. the party proceeded via Butts to the Slack. Here, just below the Inn (at about 700 ft. O.D.) and standing on the rising ground of Butts Shales, advantage was taken of the good visibility to point out the eroded dome of the Carboniferous Limestone and to note the bold escarpments of the Millstone Grit enclosing the Limestone and forming a framework to it at about 1,000 ft. O.D.

From the Slack, members walked up the steep slope of the Matlock Road to Ambervale Quarry, where a vertical face of about 80 ft. of Kinderscout Grit occurs. Here, as in many other parts of Derbyshire, the upper beds of the Kinderscout Grit are very flaggy, while the middle and lower beds are conspicuously clean, very massive and well jointed. The regional dip of the rocks on this limb of the anticline averages about 15°.

Proceeding along the scarp slope to Dutton's Quarry similar thickly bedded grit was seen, with occasional large concretions, often ferruginous. From this point, the Director called attention to the geological and physiographical features of the country to the west. Conspicuous in mid-distance was Riber Castle situated on a high bluff of Millstone Grit, while on the sky-line behind were seen the prominent Carboniferous Limestone hills, known as Abraham's Heights. Lying in the area between these two points is Matlock, which is situated on Carboniferous Limestone, through which the River Derwent cuts its way.

Leaving Dutton's Quarry, the party continued south-eastwards to Bradley Tor Quarry and the Turning Stone, one of the three natural landmarks of the district (Plate 9A). About 15 ft. high, this rock is situated on the edge of the steep scarp slope. Consisting of thinly-bedded Kinderscout Grit, the Turning Stone shows excellent current bedding and differential weathering ; these features and the origin of its isolated position were discussed by members.

From here the route lay about 450 yards S.E. to Cocking Tor, where at Robin Tor Quarry the finest exposure of the Kinderscout Grit was seen. With only 5–6 ft. of flaggy beds, as overburden, the quarry face is about 80 ft. in height and consists of clean, well-graded, massively bedded rock—10–20 ft. thick in places and well jointed. Robin Tor Quarry has been noted for over 20 years for its fine quality stone, and owing to its particularly well-graded character is very suitable for the manufacture of pulp-stones.[1] When reference was made to this quarry in September, 1945 (p. 134), work had been suspended for more than five years : from April, 1940, on the invasion of Norway by Germany. Work, however, has now been resumed both in the quarry and cutting sheds, and Mr. A. Fletcher on the present occasion kindly explained to members the working of the quarry and conducted them through the sheds.

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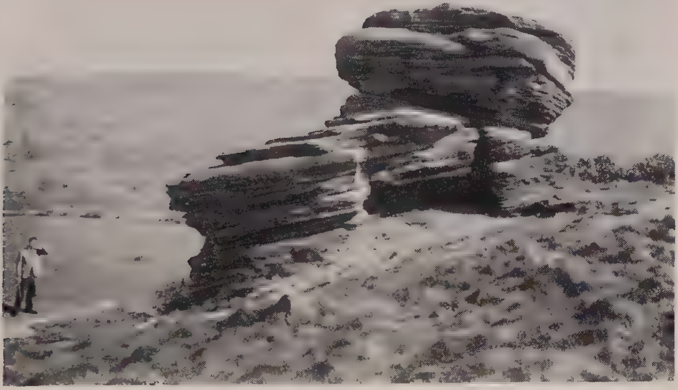
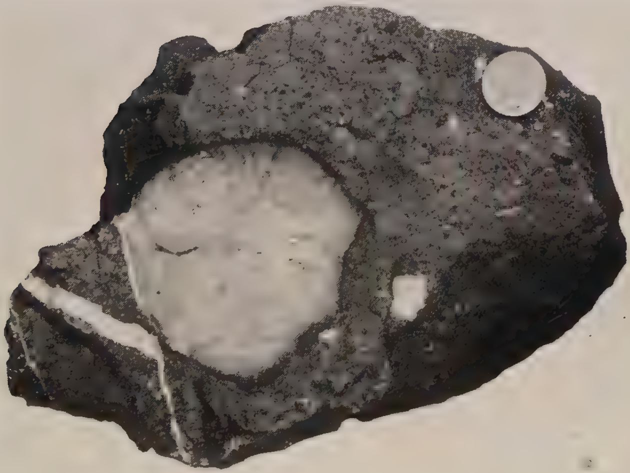
[1] Pulp-stones, most of which are exported to Scandinavia, are employed in grinding timber in the preparation of wood-pulp.



[A. J. B.

A.—THE TURNING STONE.



[J. A. Gee.

B.—INCLUSION OF CHERTY LIMESTONE IN TUFF ($\times \frac{1}{2}$).

[To face p. 138.

Here huge blocks weighing five tons and over were being cut and prepared as pulp-stones. The blocks, as taken from the quarry, are first slit parallel to the bedding into slabs of the requisite thickness; from these, cylinders of the desired diameter are cut, using rotary cutters armed with steel shot. The hole for the shaft is finally cut with a core-drill, also using steel shot. The rate of cutting of slabs is 4½ inches per hour, and of coring 9 inches per hour; the life of the stones is about a year.

From the escarpment the Director pointed out the conspicuous dome-shaped hill of Crich, which is a faulted inlier of Carboniferous Limestone; it has on its summit a tower commemorative of the war of 1914–1919.

The party then descended the escarpment and crossed the wide expanse of Butts Shales, passing en route the White Hillocks (Gregory Lode) to the Miners' Arms, where lunch was eaten on the grass behind the inn, in glorious sunshine.

After lunch, the party crossed the Amber to the road leading past the Old Spencer Lead Mine and the Greyhound Inn. About 250 yards from this point the road has been cut through Kinderscout Grit and good exposures of this rock were seen in the banks. The grit is very current bedded and the true angle of dip is difficult to measure; the bearing, however, is almost due east, showing that the party had now crossed to the opposite limb of the anticline to that which they had traversed in the morning.

Proceeding north along the farm road skirting Edges Wood to Edges Farm, the Director indicated the junction of the Butts Shales with the Kinderscout Grit. He remarked that here, like other shale-grit boundaries in the area, not only was the change in topography generally well marked, but an abrupt change in vegetation was also very distinctive: from deciduous trees (including many oaks) and sedgy grass to conifers, gorse and bracken.

Leaving the farm road at the junction of the Eastwood-Littlemoor road, the party entered East Wood for a distance of about a quarter of a mile, where other good exposures in Kinderscout Grit occur. Returning to the Littlemoor road, at the "V" bend, the junction of Kinderscout Grit and Grit Shales was crossed and exposures of the Shales were seen in the right (east) banks.

Passing over the narrow outcrop of Grit Shales, the party entered Littlemoor, which is situated on Middle Grit, and small ridges and outcrops of this rubbly ferruginous rock were noted. Continuing along Alton Lane, members recrossed the Grit Shales to the Kinderscout Grit at the Fabric. This isolated rock is, lithologically, very similar to the Turning Stone on the opposite limb of the anticline. It shows the current bedding, weathering and jointing common in the Kinderscout Grit, although some of the beds here are much more micaceous than those occurring at the Turning Stone. After some discussion at this point, members sat on the grassy slopes below the Fabric—out of the wind !—and listened to Prof. W. G. Fearnsides, who kindly contributed some remarks on the Coal Measures and newer rocks of the country to the north and east. He remarked that the outcrop of the Coal Measures in the middle distance was picked out by the line of towns and villages, while, far to the east, the rising ground, formed by the Permian, could be seen.

After thanking Prof. Fearnsides, the remaining part of the traverse was resumed along Hilltop Road to Hilltop, passing quarries in Kinderscout Grit en route. From this high ground, and with excellent visibility, exceptionally good views of the Ashover district were enjoyed. From Hilltop the party made their way back to the Square via Rattle and the Hydro in time for 5 o'clock tea.

Saturday, 20th April

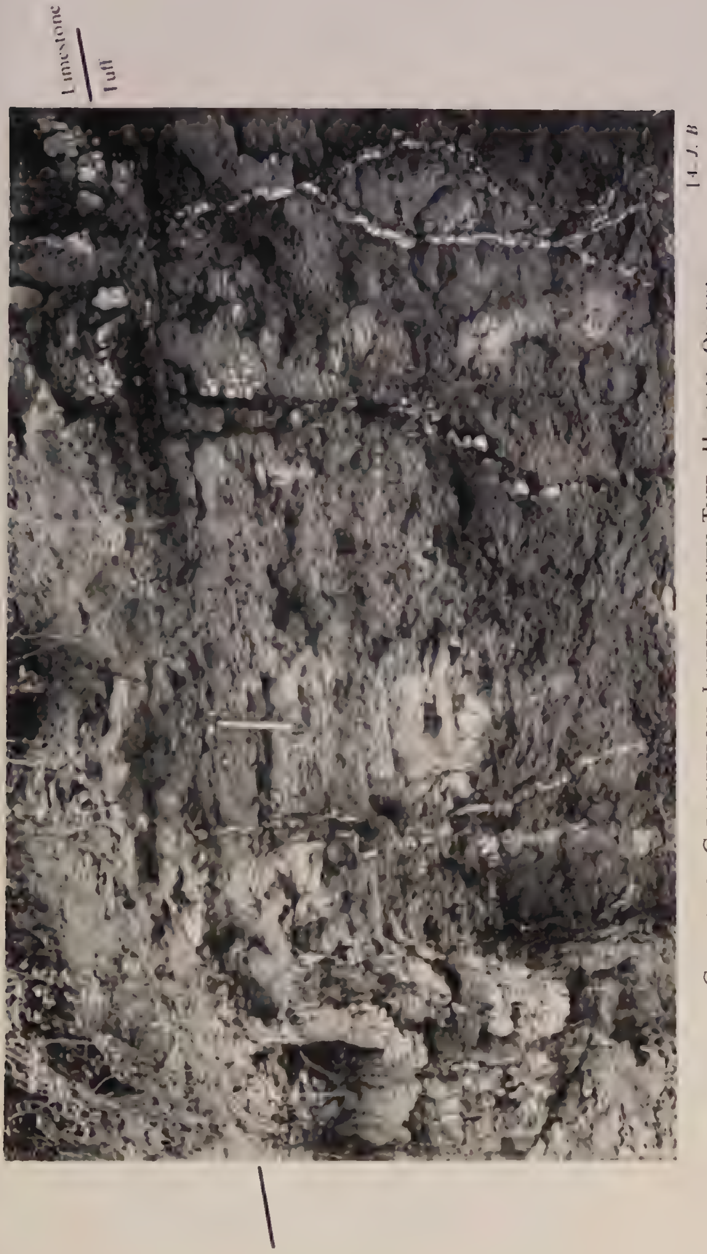
CARBONIFEROUS LIMESTONE, BUTTS SHALES AND TOADSTONE

This day was devoted to the Carboniferous Limestone and its associated toadstone, and to the chief exposure of the Butts Shales in the Marsh Brook at Butts. Having regard to the interest and importance of the palaeontology of the limestone and shales, ample time was allowed for collecting.

The party (numbering 32) left the Square at 9.30 a.m. and, by the kind permission of Dr. Gerald Fine, first visited Hockley Quarry. In his opening remarks the Director mentioned that this limestone quarry was interesting historically in that Conybeare and Phillips gave a description of it under the name " Hockley Lime Quarry " in 1822.

Although abandoned for many years and now much overgrown, the quarry still shows a remarkably clean vertical face of about 75 ft., which is practically a strike section ; the upper portion is rubbly and thinly bedded, and the lower part, massive. Attention was called to the prominent jointing and to a number of persistent chert bands in the upper beds. Replying to a question regarding the age of the limestone, the Director said that he considered D_2 was present and possibly a little of D_3, but he did not believe that D_1 occurred anywhere in the Ashover district.

After about twenty minutes the party made for the eastern entrance to the quarry close to the old lime kiln (near B.M. 523.3), where the best exposure of the toadstone (tuff) occurs. Here, in a small cutting, about 14 ft. of this rock was seen interbedded with the limestone (Plate 10). The origin and composition of the tuff were discussed, and much interest was aroused by its included fragments of chert and limestone. One block of tuff having a large rounded inclusion of limestone, 2½ inches in diameter (found by Prof. Fearnsides), is illustrated on Plate 9B.



CONTACT OF CARBONIFEROUS LIMESTONE WITH TUFF—HOCKLEY QUARRY.

[*To face p.* 140.

Returning to the road, a further good exposure of the tuff was seen alongside another old lime-kiln at Fall Hill quarries, near B.M. 515.3. Attention was here called to the dark purple colour of the soil—to which the tuff gives rise—shown in the ploughed fields opposite the exposure.

About 100 yards from this point is the main entrance to Fall Hill Quarry (B.M. 526), where Carboniferous Limestone only occurs. Immediately on entering the quarry large vertical, polished and grooved slickensides were noted ; these, the Director remarked, were the first evidence of definite movement in the Ashover district. Proceeding to the main quarry-face, much irregularity of the bedding resulting from shearing and fracturing was observed, and it was suggested that from about this point a strike fault occurred, the line of which passed through the Butts Shales at Milltown and the two Millstone Grit bands at Sheepwash Lane (see pp. 131, 132). Although evidence of movement is marked in this area, no break or shift of outcrop in either limestone or grits can be proved at the surface. Before leaving Fall Hill Quarry, specimens of fluorspar, galena, and many fossils were collected.

We are indebted to Dr. H. M. Muir-Wood for the following identifications and report.

The specimens collected by Mr. C. D. Ovey and Dr..K. P. Oakley from chalky limestone considerably below the '*Gigantella* Band,' low down in Fall Hill Quarry, Milltown, Ashover, have been identified as follows :—

Avonia sp. (*youngiana* group) C.
Avonia davidsoni (Jarosz) C.
Dictyoclostus antiquatus (J. Sowerby)
,, *hindi* (Muir-Wood) C.
,, *insculptus* (Muir-Wood) C.
Echinoconchus spp. (immature)
Echinoconchus elegans (McCoy)
,, *venustus* (I. Thomas) Productids
,, *exquisitus* (I. Thomas)
,, *punctatus* (Martin)
Eomarginifera longispina (J. Sowerby)
Krotovia aculeata (Martin)
,, *keyserlingiana* (de Koninck)
Overtonia fimbriata (J. de C. Sowerby)
Plicatifera mesoloba (J. Phillips)
Schizophoria sp. (immature)
Chonetes cf. *dalmaniana* de Kon.
Camarotoechia cf. *davidsoni* Tolmachoff
Pugnax sp.
Reticularia sp. (immature)
,, *imbricata* (J. Sowerby)
Brachythyris ovalis (Phillips)
,, *integricosta* (Phillips) (immature)
Fusella triangularis (Martin) C.
Crurithyris sp. (immature)
Hustedia sp. nov.
Actinoconchus spp. (immature)
Composita ambigua (J. de C. Sowerby)

Dielasma sp. *hastata* group.
'*Dielasma*' [? *Girtyella*] *sacculus* (Martin) V.C.
C. = species represented by 5 or more specimens.
V.C. = ,, ,, ,, 10 ,, ,, ,,

This material from Fall Hill Quarry, which is preserved in the British Museum (Nat. Hist.), includes a number of species which do not appear to have been previously recorded from the Ashover district, though all have been found elsewhere in Derbyshire in beds of D_2 age. The matrix is a light coloured limestone, often of a soft chalky consistency, from which a remarkable number of small species and young growth stages, complete with both valves, have been obtained. The larger species of *Productus*, *Pugnax* and *Spirifer* which abound in the 'Brachiopod' Beds of Derbyshire are entirely unrepresented.

The most abundantly occurring species is '*Dielasma*' *sacculus* (Martin). Investigation by transverse and longitudinal sections has shown it to differ in internal structure from *Dielasma* sens. str. and to be comparable with that of *Girtyella* Weller, species of which occur in the Mississippian of U.S.A.

It is of interest that the common species of *Eomarginifera* is *E. longispina* (J. Sowerby) which is abundant in the Scottish Lower Limestones and is rare in England and Wales. *E. derbiensis* (Muir-Wood) which is the common form of D_2 subzone of Derbyshire was not obtained.

The other common Productid species *Dictyoclostus insculptus* (Muir-Wood) also occurs more commonly in the Scottish Lower Limestones than in the D_2 beds of the Midlands and Yorkshire.

Dr. K. P. Oakley has supplied the following additional note:

The '*Dielasma*' limestone was located in situ, low down in the sequence of beds exposed in Fall Hill quarry. Specimens collected from loose blocks of the bed included, in addition to the brachiopods (listed above), the following :

Fenestella sp.
Tabulipora sp.
Pygidium and cephalon of trilobites.

At a higher horizon, but still below the *Gigantella* Band, some members found *Archiocidaros* cf. *rossica* (v. Buch).

Passing to the back of the quarry, overlooking Hardmeadow Lane, further evidence of tectonic movement was noted, and from the lane itself the Director remarked that the party were standing approximately on the Limestone-Shale junction, with the Kinderscout Grit (which they had traversed the previous day) rising in the background.

This concluded the morning's programme and members proceeded to the Miners' Arms for lunch.

About 1.30 p.m. members left their luncheon quarters and, crossing the fields below Back Lane, where small outcrops of limestone were noted, they stopped at some shallow workings in the field adjoining the grounds of Overton Hall. These limestone workings, like many others in Ashover, were re-opened and much extended during the war for their important fluorspar content. The limestone has also proved to be very fossiliferous, and members now devoted a short time to collecting.

Walking up the dip slope of the limestone to Back Lane, the party entered Cockerspring Wood. Here, about 100 yards inside the wood, are a number of overgrown quarries, one of which, however, still shows a clean vertical face about 12 ft. high. This exposure is of interest in that it probably represents the highest horizon of the Carboniferous Limestone occurring in the Ashover district. Much chert and well-defined beds crowded with *P. giganteus* occur about half way up the section and above these—at the top of the quarry—beds containing numerous *Dibunophyllum* sp. are present.

Leaving Cockerspring Wood, the party proceeded along Back Lane and turning left (south of Salter Lane) reached the Overton Hall—" Nelson " road. After a walk of about a third of a mile over Butts Shale country, they turned north (past Greenend) and crossed the fields to Butts Quarry.

Butts Quarry (see Pamphlet, p. 122) is one of the largest in Ashover. Within the last twenty years, wide and deep excavations have been made in the south-west part of the quarry (facing Hate Wood). The toadstone has recently been exposed in the floor of the quarry ; this is the most westerly exposure of the rock in the area and, moreover, is very unwelcome from the point of view of the quarryman !

The toadstone, which has been uncovered to a depth of about two feet, is much altered, pale green in colour, and somewhat plastic ; in appearance it is quite unlike that seen at other exposures.

The limestone is used as a road metal, for railway ballast and for concrete aggregates. Various forms of pre-cast articles are prepared from these aggregates, e.g. paving slabs, sections of fencing, garden seats and ferro-concrete lamp-posts. The party was met by Mr. G. Townrow, who conducted them round the casting sheds and kindly explained the method of casting on a vibrating table, with the object of improving the soundness of the product ; by this procedure, disengagement of air is facilitated and complete filling of the angles of the mould is ensured.

From this point members left the limestone inlier and proceeded to the main outcrop of Butts Shales at Butts. This exposure occurs in the banks of the Marsh Brook, which runs alongside the Kelstedge Road, near the right-angle bend of the road. The section, upwards of 12 ft. thick, consists of jet-black shales—with occasional thin beds of earthy limestone—dipping at about 30° N.N.E.

Among the fossils collected from these shales were the following : *Reticuloceras* sp., *Dunbarella* [*Pterinopecten*] sp., *Posidonia* sp., *Goniatites* sp., and many plant remains ; no trilobites were found on this occasion. A number of bullions obtained from the stream bed were broken open and from some of these " solid " goniatites were collected.

After a stay of about half an hour the party returned to the Square at about 5.45 p.m.

Sunday, 21st April

Morning: There was no organised programme. A good deal of miscellaneous collecting was carried out by certain members of the party, while others took a general view of the ground which had already been covered and examined details which were necessarily glossed over on the previous days.

Afternoon: THE KINDERSCOUT AND MIDDLE GRITS, NORTH AND WEST OF KELSTEDGE

Leaving the Square, Ashover, soon after 2.30, a party of 26, under the direction of G. W. Himus, proceeded to Kelstedge, where a contingent of three from Matlock and one from Kelstedge joined. A short halt was made here, and the Director pointed out that the afternoon's traverse would be made over an area almost solely of Millstone Grit, but, owing to the fact that the detailed structure was not known it was not feasible to circulate a geological map. With Mr. Sweeting he had carried out some preliminary mapping, but there were so many unsolved problems that it would be premature to draw anything more than the most tentative of boundaries. There was evidence of extensive faulting, and it was obvious that the structure was considerably more complicated than that of the Ashover inlier.

The Director drew attention to the view across the valley of the Amber ; to the south-east the bold escarpment of the Kinderscout Grit formed a striking feature. Farther north, however, the principal escarpment is that of the Middle Grit, culminating in the Wirestone ; the Kinderscout Grit forms a comparatively inconspicuous mass. Still farther to the north, near Gladwin's Mark, the escarpment of Middle Grit dies away, while a little to the east of that point the Kinderscout Grit forms a strong feature impending over Peasunhurst.

Just to the north of Kelstedge there is a bluff of grit, rising high above the village, and a move was made to examine it. The party therefore followed Kelstedge Lane, and at the junction with Oak Lane attention was drawn to the gulley which extends from a little below Hardwick Farm to the Amber, dividing the bluff into two nearly equal halves. Dr. Himus said that he was unable to explain the significance of this gulley ; to the west of it the bluff consisted of Middle Grit, what there was to the east was not settled owing to lack of sections. He would like to find that the gulley followed a fault between Middle and Kinderscout Grit, but in the absence of sufficient data no decision could be made.

The next stop was at the old quarry at Brockhurst. An excellent view was obtained here and the features of the escarpments already referred to could be well seen. The quarry is an old working in Middle Grit and illustrates the characteristics of that formation.

The rock is rusty red in colour, rubbly above and more massive below; pebbly bands are conspicuous in this portion. The bedding and jointing are much less regular than in the Kinderscout Grit, the result being that the whole aspect of the workings is messy and irregular. There are none of the large, clean, flat working faces which one associates with quarries in the Kinderscout Grit. There is, too, a plentiful growth of gorse and heather both in and around the quarry. These are not met in anything like such profusion on the Kinderscout Grit in the district round Kelstedge. The Middle Grit at Brockhurst dips at 24 degrees, approximately south-west.

The Director pointed out that one of the difficulties experienced in mapping the area arose from the fact that although it was possible to distinguish Kinderscout from Middle Grit in large sections, in small surface workings and in hand specimens discrimination was much more difficult. No identifiable fossils having been found, in an endeavour to obtain better evidence than is supplied by mere *appearance*, it is proposed to make a petrological study of the grits in the neighbourhood, with a view to establishing (if possible) some reliable criteria by which they can be identified with certainty.

From the quarry a descent was made to the bed of the Smalley Brook, where, about a hundred yards above Brockhurst Mill, a cliff about 30 ft. high was seen in the right bank of the brook. The lower 15 ft. of the cliff show a good section in thinly-bedded dark grey, micaceous grit with thin shaly bands. This, on lithological grounds, must be taken as Upper Kinderscout Grit. It can be followed upstream for nearly a quarter of a mile, and downstream as far as the confluence of the Smalley Brook with the Amber ; it is also seen at the top of the bluff above the Amber a little farther downstream. At the cliff the dip is 7 degrees, a little south of east. Farther down the stream, dips from 18 to 40 degrees, varying in direction from north-east through south to west, have been observed. Little significance is attached to the amount or direction of these dips ; the upper part of the Kinderscout Grit is strongly current-bedded and very varied dips can be observed even in small sections.

The Director said that he was of the opinion that the Middle Grit of the bluff was faulted against the Kinderscout Grit and that the Smalley Brook followed closely the line of the fault. The Middle Grit is certainly out of place in the bluff and its position here can scarcely be explained by any conceivable system of folds.

The upper portion of the stream is difficult for a party to follow ; there are numerous obstructions, in places the valley narrows almost to a gorge and the ground is apt to be marshy, hence Brockhurst Lane and Buntingfield Lane were traversed, and near Stanfield House the party returned to the Smalley Brook to inspect a section of about 10 ft. of Boulder Clay (which must here attain a thickness of at least 20 ft.). The main section shows 8 ft. or more of dark grey clay containing many pebbles and blocks of grit, with a smaller proportion of limestone and chert. This rests on about 2 ft. variegated grey and brown sticky clay, containing small pebbles (chiefly of grit). The variegated clay can be detected over a wide area, reaching nearly to Uppertown on the west, and to Clark Barn to the north-east. Some discussion took place here, the fact that no striated pebbles were found, and that all the included materials were of local origin was held to indicate that the deposit was not a true boulder clay, but the result of local sludging of surface materials by snow. While the argument was at its height, Dr. J. A. Richardson produced a block, about 4 in. cube, which he had just extracted from the Boulder Clay. This specimen has since been sectioned and the following report has been kindly supplied by Dr. R. M. Shackleton :

> The thin section shows this to be an andesitic volcanic rock. It contains evenly scattered euhedral and subhedral plagioclase phenocrysts of various sizes, together with a few chloritic pseudomorphs after pyroxene with which are associated grains of leucoxenised ilemnite, and small prisms of apatite. The groundmass is pale brown, decomposed and generally structureless, but the arrangement of decomposition products in sinuous streaks and patches suggests flow structure. Epidote granules are plentiful both in the felspars and in the base. In addition, there is a faint web of sericite throughout the base which indicates incipient flow-cleavage. It may be inferred from this that the rock is of Lower Palaeozoic age. A few small and sharply defined fragments of andesite of slightly coarser texture seen in the slide suggest that the rock might be pyroclastic, but the flow structure suggests rather that it is a lava.

Since no andesitic lavas are known in Derbyshire, the derivation of the boulder clay is not entirely local. The nearest known localities of andesite are in North Wales and the Lake District ; the probable minimum distance from which the block has travelled is therefore defined. The boulder clay will undoubtedly repay careful detailed study.

The walk was then resumed by cart track to Dryhurst, whence the conspicuous bluff of Kinderscout Grit above Peasunhurst could be seen to the west. The Director said that he had found Kinderscout Grit for some distance in the banks of the upper part of the Hodge Lane Brook (headwaters of the Amber) to the south of Peasunhurst, while about a quarter of a mile east of Dryhurst, flaggy Upper Kinderscout Grit had been found in a small stream. He also drew attention to a low escarpment running north-west south-east on which Dryhurst stands. This was presumably formed by Kinderscout Grit, but except for the exposure mentioned above no sections had been seen.

Looking north-eastwards, a conspicuous, steep bluff, heavily clad with gorse and heather, could be seen overshadowing Alicehead ; between this and Dryhurst is a shallow, sedgy hollow, presumably occupied by Grit Shales, and probably with a top-dressing of Boulder Clay. Crossing the hollow, the party soon entered the old workings in the bluff. These are in typical Middle Grit, which exhibits all the characteristics previously mentioned. The dip is 20 degrees, approximately north-east. To the north-west, the escarpment of Middle Grit dies away and presumably the outcrop turns to the west and joins with that somewhere near Gladwyn's Mark. The bluff over Alicehead rises approximately from the 1,000 ft. contour to a height of about 1,040 ft. On the older edition of the six-inch map, a triangulation point was shown at the summit of the bluff ; on the latest edition (1923), however, this point is no longer marked, nor is any elevation shown. Professor Fearnsides explained that the triangulation points at the Turning Stone and Alicehead had been removed since it was found that both sites were slipping and were therefore unsuitable as " fixed " control points (Plate 11).

North-eastward from Alicehead, the escarpment rises somewhat above the 1,000 ft. contour and is continuous as far as Spitewinter, which was next visited. Here, old workings were seen on both sides of the main Matlock-Chesterfield Road. The quarries were seen to be in biscuit-coloured grit, flaggy at the top, but massively-bedded lower down and showing clean, smooth, vertical working faces. At and around Spitewinter, therefore, there is Kinderscout Grit. Mapping by feature would (and has) resulted in the escarpment from Alicehead to Spitewinter being plotted as all in Middle Grit. The Director said at this point that he had brought the party by the route they had followed on account of the fine object lesson in the dangers of feature-mapping without frequent check by reference to exposures. The only conclusion that can be drawn is that the Middle Grit and Kinderscout Grit are brought into contact between Alicehead and Spitewinter by faulting.

The party next walked by road to Stone Edge (locally known as " Stannedge "), where there is a large abandoned quarry in cherry-red Upper Grit or Rough Rock. This grit is harder and less friable than the Middle Grit, which can generally be broken down to its constituent grains in the hand. The colour is less " rusty " than that of the Middle Grit and the jointing more regular, so that working faces are reminiscent of those in quarries of Kinderscout Grit. Standing high above the road is a conspicuous pinnacle of grit on which Professor Fearnsides drew attention to curious vertical and horizontal flutings, which, he suggested, were the result of wind-action on an irregularly wetted surface. He also pointed out numerous tiny points on the surface of the pinnacle which glistened brightly in the evening sunlight ; these, he said, were not small flakes of mica, but facets of crystals of secondary quartz which had grown round the original grains of the rock.

A move was then made to the headwaters of the Press Brook, near Highashes Farm, where a small section was seen in black shales, below which was a thin band of coal.

The return to Ashover, where the party dispersed at about 6.45, was made by road ; it had been hoped to follow a track to Hilltop across the fields, but this had been in large part ploughed over, so was not available.

Monday, 22nd April

ASHOVER HAY, RAVENSNEST AND WIRE STONE AREA

Making a prompt start at 9.30 a.m. the party (32 in number) walked down Hollow Lane (alongside the Red Lion Hotel) and, crossing the Amber, entered Salter Lane. Here the toadstone has its maximum width of outcrop (about 220 yards) and good exposures of the rock were seen in the bank of the road. Walking up the flagged footpath, members reached The Drive, where, about half-way down, the toadstone was again seen. It is here, alongside Cockerspring Wood at approximately 650 ft. O.D., that this rock reaches its highest elevation in the district.

Proceeding along The Drive to its eastern entrance (above Demonsdale Farm), the last exposure of the toadstone was seen, where, in a cutting in the bank—close to the gate—the uppermost part of the rock is covered by rubbly limestone.

Leaving The Drive, members made their way to Fall Gate Quarry. This quarry, like that at Butts, is in Carboniferous Limestone, but the rock is more rubbly and not so regularly bedded as that seen at the north-western limit of the inlier, jointing and slickensiding being much in evidence. In addition to its road metal, Fall Gate Quarry is also worked for fluorspar, where the mineral is screened and washed on the spot.

The palaeontologists in the party obtained a very interesting series of fossils from this quarry, and among them Dr. Oakley and Mr. Ovey report the following identifications which were made by members of the staff of the British Museum (Natural History) :—

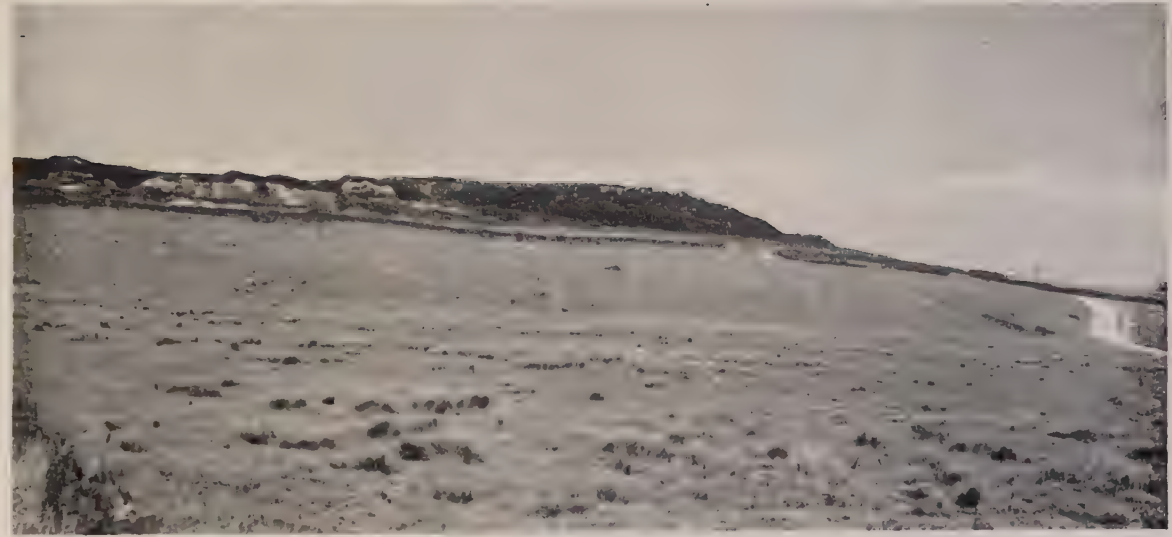
One of the greenish marly bands (bentonitic ?) near the base of the section yielded abundant bryozoa, mainly *Fenestella* spp. and *Stenophragma* sp.—also some corals, including *Syringopora*, and brachiopods, including *Hustedia* sp.

A loose block of chalky limestone with ‘ *Dielasma*,’ evidently from a higher horizon than the bryozoa bed, yielded the following brachiopods (identified by Dr. Muir-Wood) :

Echinoconchus elegans (McCoy), *E.* sp. immature ; *Overtonia fimbriata* (J. de C. Sow.) immature ; *Camarophoria* sp. ; *Brachythyris* sp. immature ; *Crurithyris* sp. immature; *Spiriferellina octoplicata* (J. de C. Sow.); ‘ *Dielasma* ’ [? *Girtyella*] *sacculus* (Martin).

A sample of this bed was broken down and washed by Mr. C. D. Ovey who extracted the following micro-fossils, etc.

Ostracods
Serpula sp.
Spirorbis globosus McCoy



[A. J. B.

BLUFF OF MIDDLE GRIT, ALICEHEAD.

[*To face p.* 148.

Fenestella sp. (fragments)
Hexactinellid spicules
Valvulinella palaeotrochus (Ehrenberg)
Endothyra bowmani Phillips MS., Brown
? *Saccammina* sp.

Other specimens collected in this quarry included :

Tooth of *Petalodus acuminatus* (Ag.) found by Mrs. Robertson and plates of *Archiocidaris* cf. *rossica* (v. Buch).

A bed of unusually large crinoid stems (mostly 20-22 mm. in diameter) was observed high up on the northern face of the quarry. Following a suggestion of Prof. Fearnsides that a weathered portion of this bed of " Derbyshire Screws " was worthy of preservation, Brigadier-General Jackson subsequently arranged for the foreman of the quarry, Mr. Townrow, to have a slab quarried out and sent to the Department of Geology, British Museum (Nat. Hist.), as a donation from the Clay Cross Company Ltd.

From here the route was due south to Oakstedge Lane, Milltown, crossing the Amber by the bridge at the Miner's Arms. On reaching the lane, the party turned east to Rosetree House, at the junction of Sheepwash Lane and Brown Lane. From some old quarry exposures in Kinderscout Grit, just north of the house, the conspicuous " swing " of the two Millstone Grit bands was well seen. Attention was also called to the abrupt turn of the Amber in the Butts Shales (south of the Miner's Arms), and to its subsequent course through the Kinderscout and Middle Grits to the east. It was suggested that these features were related to the movement observed at Fall Hill Quarry, and that the party were now standing near to the S.E. end of the inferred fault (p. 132).

Returning to Oakstedge Lane, situated on Butts Shales, members walked south to the junction of the road leading to the Methodist Chapel. Here, good exposures of the shales were seen in banks of the road and discussion took place regarding the sudden lithological change from a shelly limestone to a black shale and the exact time at which this break occurred.

At this point Mr. G. Bond drew some comparisons with an area he was studying in North-West Yorkshire, saying :—

> It is interesting to compare the limestone dome at Ashover with some of the structures found in the Craven Reef Belt of Yorkshire, between Cracoe and Grassington. The age of the Ashover Inlier has been clearly demonstrated during the field meeting, advanced Dibunophyllids, large *Palaeosmilia* cf. *Murchisoni* and *Lonsdaleia* sp. all pointing to a D_2 age. The apparent absence of *Orionastraea* makes it doubtful if the highest part of this sub-zone is reached, while no trace of the *Girvanella* band or of *Davidsonina* (*Cyrtina*) *septosa* was found, showing that the lowest exposures do not reach down into D_1. The fauna of the limestone has a distinctly ' reefy ' character, including as it does, trilobites, lamellibranchs, gastropods and brachiopods such as *Dielasma*, *Pugnax*, semireticulate and pustulose Productids. No goniatites diagnostic of P horizons have been found in the limestones of Ashover.

The similarity does not end with the fauna. The dome shows in a subdued way the quaquaversal dips found on some of the Craven Reef knolls where the highest horizon represented is also some part of D_2. It is not suggested that the Ashover dome is a reef knoll, but there is a similarity. The thinner bedding and lower dips make the structure much more obviously tectonic that those at Cracoe.

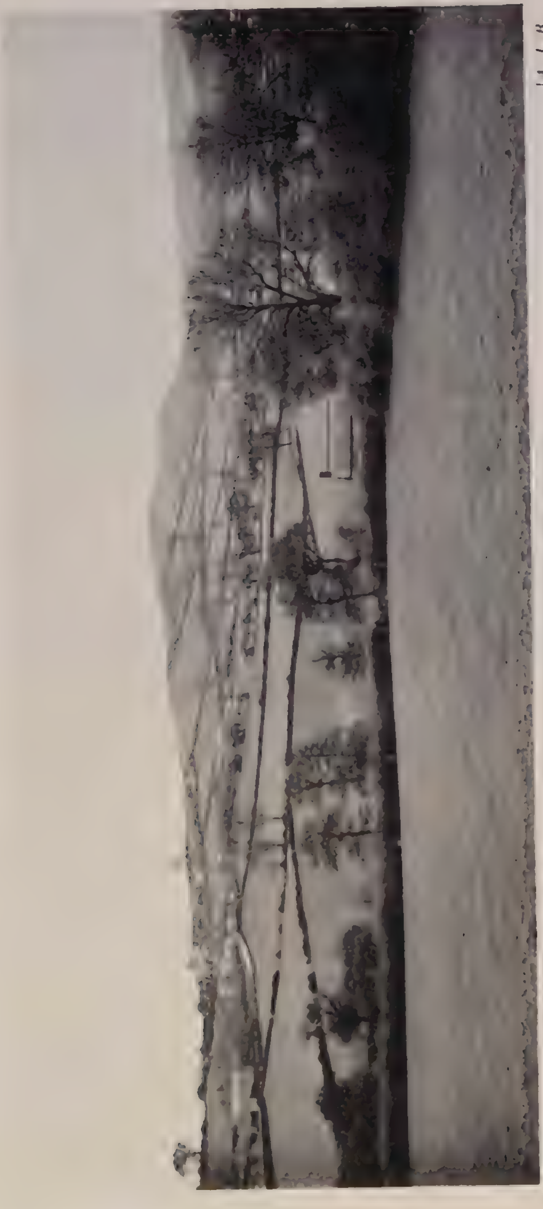
I was interested in the suggesion that part of the folding took place before the deposition of the Butts Shales. This would indicate movement at or near to the end of D_2 times. At Cracoe, these movements (Sudetian I or II) were very strong;and were followed by much erosion of the resulting fold structures, so that the Bowland Shales rest with marked unconformity on the limestone, and many of the dips in them are due to compaction on an uneven floor. In terms of goniatite zones the break at Cracoe is of short duration. At Ashover they indicate a considerable break, though the physical evidence is much less striking. It would be interesting to know whether the break occurs at the top of the limestone, as at Cracoe, or by non-sequence within the Butts Shales themselves. The present exposures do not appear to be adequate for a solution of this problem.

The party thanked Mr. Bond for his interesting comments, and then walked up Chapel Lane, turning south along the footpath over the summit of Ashover Hay. The " Hay " is a long whale-back hill with a wide bulge at its southern extremity. Although rising only about 720 ft. above sea level, it makes a conspicuous feature in the south-eastern part of Ashover. The hill consists of Kinderscout and Middle Grits with steep easterly dips, and is bounded on the east and west by flat shale areas (Plate 12).

Descending the Hay at Knottcross Farm, the party returned along Oakstedge Lane to Milltown for lunch, noting on the way some " step " landslips on the hill-slopes opposite Hole Wood.

After a lunch interval of about 45 minutes, members proceeded via Oakstedge Lane and Raven House Farm to the area west of Hole Wood. Here, near the base of the Kinderscout Grit escarpment and at the grit-shale boundary, large landslips occur, one of which forms a prominent hillock alongside Hole Wood. Between this landslip and the escarpment is a deep flat depression consisting of siliceous shaly material. Discussion arose regarding its origin and of similar large landslips occurring in Edale (Derbyshire) and the Isle of Wight. Dr. Himus said he was well acquainted with a landslip of similar appearance and dimensions at Luccombe (Isle of Wight). In the spring of 1910 a great mass of the Sandrock division of the Lower Greensand foundered seawards over a band of clay above the Ferruginous Sands, giving rise to a ridge which was separated from the cliff by a deep hollow closely resembling that near Hole Wood.

From the Hole Wood area to Ravensnest and beyond (a distance of nearly a mile) landslipping is common, producing a series of mounds and bluffs. The consequent uneven and hummocky character of the surface, which consists of Butts Shales, is responsible for much marshy and boggy ground. This area was



[J. B.

ASHOVER HAY FROM MILLTOWN.

[*To face p.* 150.

now crossed by the party, who eventually reached the old mine tips (White Hillocks) after " collecting " much shaly-mud en route !

A pause was made here to examine and obtain specimens of galena, zinc blende (sphalerite), pyrite, fluorspar, etc. These old mine tips cover an extensive area and work on them for their fluorspar content is now being actively undertaken by Mr. John Parkin, of Ravensnest.

Leaving the White Hillocks, the party walked through the wood overlooking Overton Hall, keeping close to the grit-shale boundary and noting large blocks of Kinderscout Grit lying on the scarp slopes and on the flat shale fields below.

Crossing to the road near Hatchley's Farm, attention was called to a small exposure of Butts Shales in the bank, and from here members continued along the road to Eddlestow cart-track via the Nelson Inn and Slack.

The route now lay past Eddlestow Farm across boggy grit shales to the Wire Stone. This, the third of our natural landmarks, lies at a height of approximately 1,000 ft. O.D., from which good and extensive views of the Darley Dale country to the north were obtained.

The return to Ashover was made via the old Wirestone Quarries in Middle Grit, along the road and footpath past Vernon Lane Farm leading to Eddlestow Wood (" The Trossachs ") and Kelstedge. In Eddlestow Wood evidences of rejuvenation of the Amber and its accompanying river terraces were noted and discussed. The party then made for the Square, Ashover (via Kelstedge Lane), where the meeting concluded at about 5.50 p.m.

While members were having lunch, Dr. A. J. Bull took the opportunity of proposing a vote of thanks to the Director in a felicitous speech. He said (amongst other things) that what had impressed him was the convenient way in which the daily traverses had come into immediate proximity to the Miners' Arms at lunch time ! Mr. Sweeting had made it clear that even in a district of simple structure, like that round Ashover, there were a number of detailed problems which still awaited solution. Even when an area had been mapped on a large scale, and when the geology could be said to be well understood, there was always room for further work ; finality never was and never could be reached. There were always further details which could be elaborated as the result of extended study. The vote was then put to the meeting and carried with acclamation.

The Authors take this opportunity of acknowledging their indebtedness to Dr. A. J. Bull for the excellent photographs from which Plates 8, 9A, 10, 11 and 12 have been prepared, and to Mr. J. A. Gee for that on Plate 9B.

EXPLANATION OF PLATES 8—12

Plate 8.—General view of Ashover looking south. In the foreground are the Butts Shales, middle distance shows the Carboniferous Limestone, and the sky-line, Millstone Grit.

Plate 9A.—The Turning Stone. An isolated residual mass of Kinderscout Grit, showing erosion and current bedding.

B.—Inclusion of cherty limestone in Tuff (α ½).

Plate 10.—Contact of Carboniferous Limestone with tuff, Hockley Quarry, showing veins of fibrous calcite.

Plate 11.—Bluff of Middle Grit, Alicehead. Foreground, boulder clay presumably overlying Grit Shales.

Plate 12.—Ashover Hay from Milltown. In foreground, Butts Shales.

THE PRIMARY AND SECONDARY ELEMENTS OF A FAULT

By JOHN CHALLINOR, M.A., F.G.S.

I. INTRODUCTION

THE numerous elements and quantities involved in a fault-structure are rather confusing in the mass, but when they are classified into those that are primary and those that are secondary, on the lines suggested for folding in a previous paper (Challinor 1945), they can be dealt with more easily and in a more rational manner. For purposes of analysis, then, we consider the structure firstly as quite independent of any outside frame of reference and secondly in its relation to the earth's surface.

Suppose a series of uniformly dipping beds to be cut by one fault-plane, all surfaces thus being plane (and of indefinite extension), and let any relative movement of rotation be excluded so that the beds on both sides of the fault remain parallel to each other. It is this simple arrangement that will be considered in the present paper, but the same general principles would apply in the more complicated cases of compound faulting and of curved surfaces and rotary, or irregular, movements.

II. PRIMARY GEOMETRICAL ELEMENTS

The primary geometrical elements of a fault are given completely by one angular and one linear quantity :—

1. The plane angle made by the bedding with the fault.
2. The separation of the bedding-planes due to faulting.

If any one bedding-plane be taken we have the two traces of this plane on the fault-plane. These lines will be referred to here simply as the " traces."

III. MOVEMENT ON THE FAULT-PLANE

The actual path of relative movement on the fault-plane is of course a primary element of the fault. A knowledge of the two positions of a point, before and after faulting, would give the net relative movement in a straight line. But this cannot be inferred from the resulting geometrical relations of the planes. If, however, we eliminate secondary elements by ignoring the earth's horizon and consider only a direct view of the fault-plane our knowledge of the matter becomes clear.

A very simple figure (Fig. 20) shows the range of possibilities as to this movement. This figure is similar in appearance to that given by Stočes and White (1935, Fig. 391) but that figure is stated to be a section (presumably a vertical section) and so the possible paths of movement indicated would represent projections, on to the vertical plane, of movements on a plane not specified. The "section" may, however, be intended to represent a direct view of a fault in the special case where it is vertical. This is mentioned as an illustration of the confusion that is apt to arise when the primary condition is not separated from the secondary, the simplest and most general facts and inferences about the fault being hidden beneath a cloak of complicated special and secondary considerations. Incidentally an equally simple figure (Fig. 21) solves the problem of finding the path and amount of net relative straight-line movement when two non-parallel planes are simultaneously affected by the faulting.

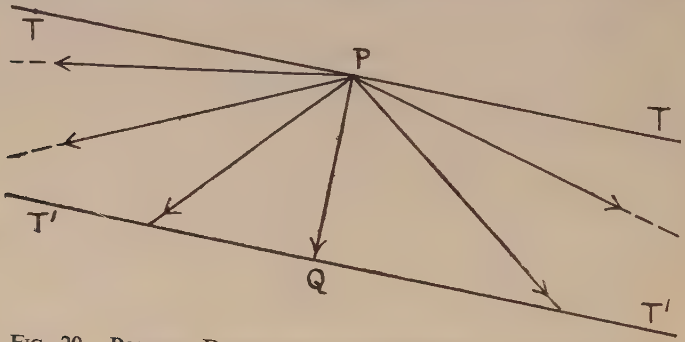


FIG. 20.—POSSIBLE DIRECTIONS OF MOVEMENT ON A FAULT-PLANE.

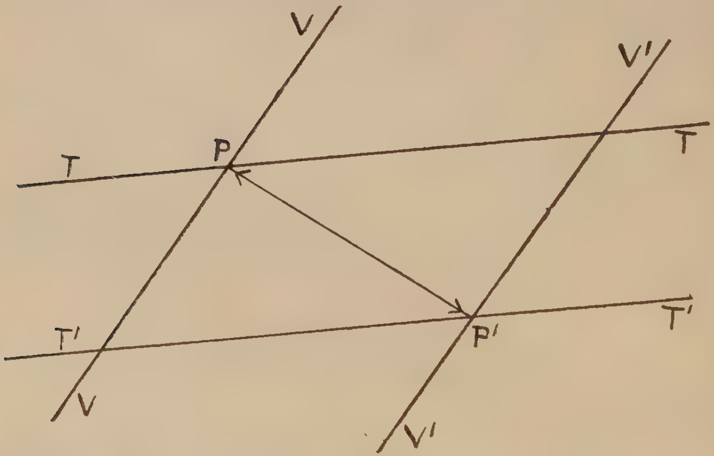


FIG. 21.—DIRECTION OF MOVEMENT ON A FAULT-PLANE WHEN TWO INTERSECTING PLANES ARE AFFECTED.

IV. THE PLANE OF NORMAL SECTION

In the consideration of imaginary planes cut through a fault-structure let it be understood that " one plane " means any plane of a series of parallel planes.

Across the primary fault-structure there is one plane (and only one) which, being the plane normal to the traces, is perpendicular to both the fault-plane and the bedding (see Fig. 22). This plane will be referred to here as the " plane of normal section." It is in this plane alone that the relations between the two dissevered parts of any bedding-plane, and that between them and the fault-plane, are, both together, properly shown ; that is, the length of the line perpendicular to the sections of the two parts of a bedding-plane is the true separation of the bedding, and at the same time the angle between the sections of bedding-plane and fault-plane is the true plane angle. In no other sections of the fault-structure do these conditions hold.

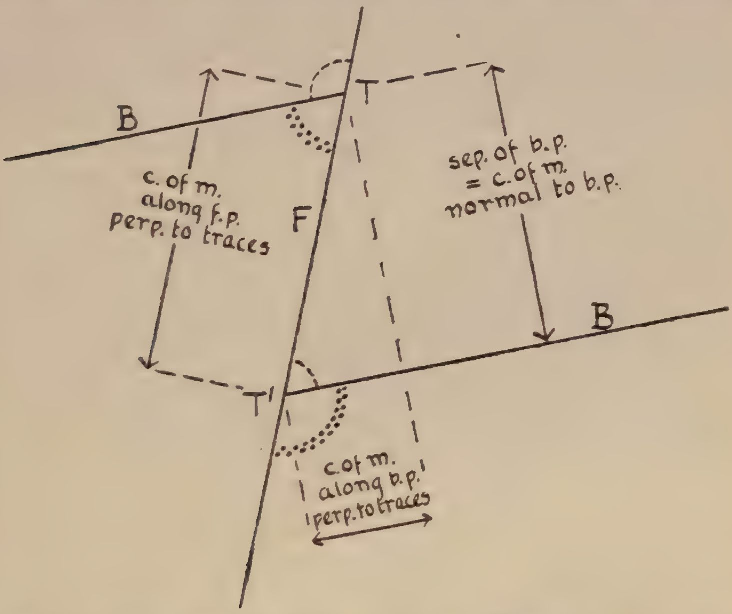

B
T
sep. of b.p. = c. of m. normal to b.p.
c. of m. along f.p. perp. to traces
F
B
T'
c. of m. along b.p. perp. to traces

Fig. 22.—Section Across a Fault in a Plane Normal to the Traces.

We can measure the amount of the component of relative movement in any direction lying in the plane of normal section but in no other direction. Thus we know the component of (relative) movement along the fault-plane perpendicular to the traces, and the amount of separation of a bedding-plane, in a direction normal to itself, is also a measure of the component of movement in that direction. Again, we can measure the component of movement along the bedding-plane perpendicular to the traces and this tells us whether there has been compression (shortening) or tension (lengthening) in the plane of the bedding.

It is thus evident that this plane holds a unique place in the primary fault-structure and so we are prepared for its special importance as a plane through the fault-structure when that is in any particular position.

V. SECONDARY ELEMENTS

The primary elements of a fault being given, all the secondary elements arise from the particular setting of the fault-structure in relation to the earth's horizon.

The more significant secondary geometrical elements are strikes and dips and certain vertical and horizontal measurements such as vertical separation, throw and heave. These are discussed in numerous works of which the following may be mentioned : Reid and others 1913, Challinor 1933, Willis and Willis 1934, Straley 1934, Gill 1935, Stočes and White 1935 and Haddock 1938. It is not intended to make any further comments here except to emphasise that they are geometrical quantities and not components of movement, though in certain special cases such a quantity may happen to be such a component.

It will be realised that secondary quantities all change their values if the fault-structure be tilted bodily by subsequent earth-movement but that primary quantities change only if the fault-structure be subsequently deformed.

VI. SECONDARY CATEGORIES

Any particular primary fault-structure may be either a strike-fault or a dip-fault. When set with the traces horizontal it is a strike-fault. To imagine it set as a dip-fault is perhaps hardly so obvious. The dihedral angles between the dissevered parts of a bedding-plane and the fault-plane (see Fig. 22) can be cut obliquely by certain planes (a series of non-parallel planes) so that the intersections form (four) right-angles. If the whole be now set so that these right-angles lie horizontally the structure becomes that of a dip-fault. The matter may be, at least partially, demonstrated in another way : if we start with a primary structure set as a dip-fault we can imagine it to be revolved until the traces become horizontal, when it will be set as a strike-fault (see Fig. 23).

Again, a fault-structure may be (geometrically) " normal " or " reverse " according as to how it is set (see Fig. 24). It should be borne in mind that not only do we not know the path of the move-

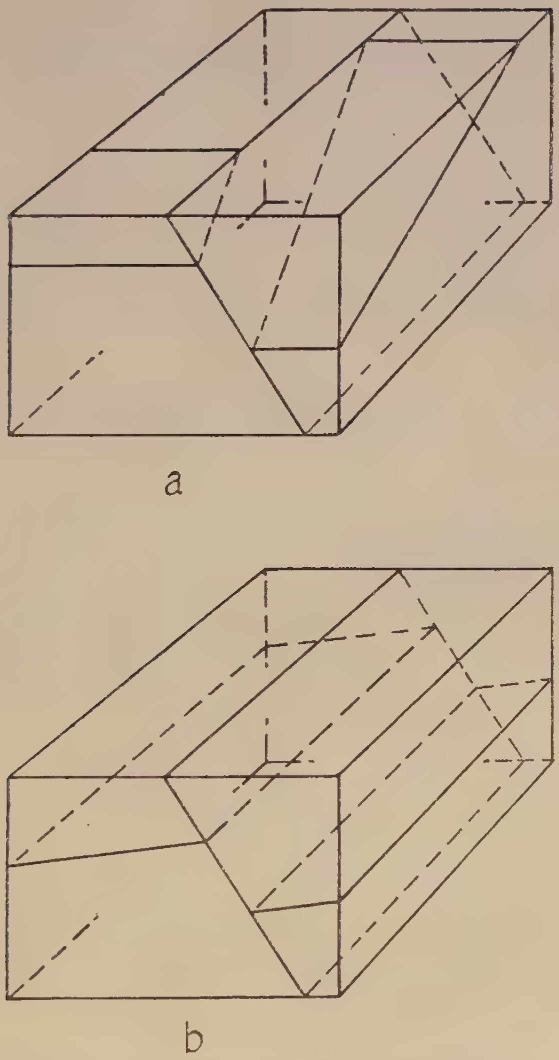


Fig. 23.—Block-Diagrams of One Primary Fault-Structure: (a) Set as a dip-fault and (b) Set as a strike-fault.

ment on a fault-plane (either side may have moved, obliquely, relatively upwards or downwards in either a " normal " or a " reverse " fault) but still less do we know the direction of stress causing the production of the fault-plane and the movement along it.

We thus see that certain categories which might at first sight appear to depend on essential distinctions in the relation between fault-plane and bedding are in fact dependent merely on the relation between the fault-structure as a whole and the earth's horizon.

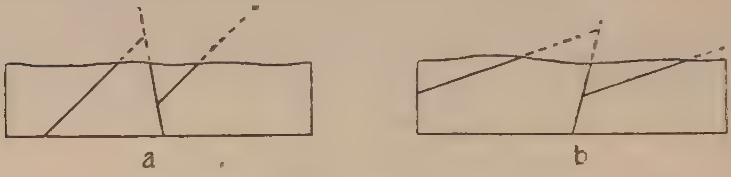


Fig. 24.—Two Settings of One Vertical Section Across a Fault.

VII. THE PLANES OF SECTION THROUGH THE SET FAULT-STRUCTURE

We have already seen that there is a unique plane of section, the plane of normal section, that truly shows the primary elements of a fault. When the earth's horizon is taken into consideration other planes assume special positions. These are shown in Willis and Willis (1934, Figs. 197-202). One of them is our plane of normal section, but these authors remark (p. 508) : " measurements in the plane perpendicular to the trace of the [bedding] and the fault plane are practically confined to mining practice and were not considered by the Geological Society of America Committee." Far from it deserving any such neglect from the theoretical point of view it is the one section of essential importance.

The sections usually taken across a fault are the vertical section normal to the strike of the fault, the vertical section normal to the strike of the bedding and the horizontal section. There are only two cases in which any of these are of significance in revealing primary elements : (1) in a strike-fault (including the cases of either horizontal bedding or a horizontal fault) the two vertical sections are the same and also coincide with the normal section and (2) where both bedding and fault are vertical the horizontal section will be the normal section.

VIII. DETERMINATION OF THE PLANE OF NORMAL SECTION FROM A MAP

The map or plan of a fault on a surface of known relief, with the dips of bedding and fault recorded, fixes all the elements of the structure. From these data the plane of normal section can be determined and the section itself drawn (see Fig. 25).

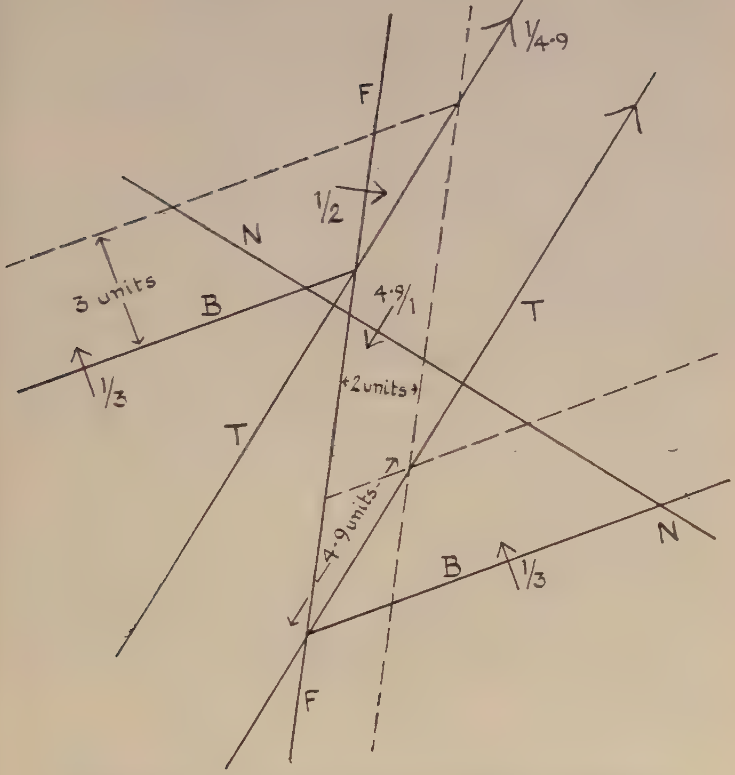


FIG. 25.—PLAN OF A FAULT ON A HORIZONTAL SURFACE.

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EXPLANATION OF FIGURES 20-25

FIG. 20.—If the plane of the paper represent the fault-plane and TT and T′T′ the two traces of a bedding-plane then a point on T′T′ which was originally at (immediately adjacent to) P on TT may have moved, relative to P, in

any direction in the fault-plane on the one side of TT, such as the directions shown by the arrows. Similarly, the possible relative movement could be shown of a point on TT originally at a point on T′T′. The amount of movement necessary to cause the observed separation along the fault-plane depends on the direction of movement. The component of movement, PQ, along the fault-plane perpendicular to the traces is known, but the component of movement in any other direction along the fault-plane is not known.

FIG. 21.—The diagram is similar to Fig. 1, with VV and V′V′ the two additional traces. It will be apparent that the point P′, originally at the position P, can have moved, relative to P, only to the position P′; and the point P similarly from P′ to P.

FIG. 22.—In this normal section F is the fault and B a bedding-plane (in two parts) and the points T and T′ the two traces. Four three-dimensional angles ("dihedral angles") are made between the bedding-plane and the fault-plane. They form two pairs of adjacent supplementary angles and also two pairs of corresponding supplementary angles, the latter pairs being indicated. The component of movement is known for any direction in this plane, the more significant directions, mentioned in the text, being indicated (b.p., bedding plane; f.p., fault-plane; c. of m., component of movement). This two-dimensional figure will at once assume its third dimension when it is realised that we are looking along both the fault-plane and the bedding-planes (and the traces); that is, with perspective ignored, we are not looking obliquely at any of the geometrical elements.

FIG. 23.—(a) shows a dip-fault. Imagining the fault-plane, with the whole structure, to be revolved about an axis normal to itself so that it remains in the same position until the traces become horizontal, then the same primary fault-structure becomes a strike-fault, as in (b). The dip-fault-structure might be imagined as revolving about any axis, and a strike-fault would be attained in some position. The two rectangular blocks, drawn with their upper and lower surfaces horizontal, must be considered as having been separately hewn out of the fault-structure in its two positions. The fault-plane and the two dissevered parts of a bedding-plane are shown within each block.

FIG. 24.—The base-line is horizontal in each of these two settings of one vertical section across the same primary fault-structure. In (a) the net result of the shortened bedding and the separation of the beds is a horizontal lengthening along the line of the section; it is a normal fault. In (b) the net result is a horizontal shortening; it is a reverse fault. Such sections are usually taken along the dip of the fault. The fault-plane and one (dissevered) bedding-plane are shown in each section.

FIG. 25.—This plan is the horizontal section through the fault-structure. If F be the fault and BB a bedding-plane (in two parts), with dips (tangent-gradients) of 1/2 and 1/3 as shown, TT will be the projections of the two traces on to the horizontal plane. These lines will incline as shown at an amount of 1/4.9. The plane of normal section will thus be a plane of which the strike, N, is perpendicular to T and of which the dip is 4.9/1 as shown. The vertical section parallel to N, projected on to this plane, will coincide with the normal section; and a method of drawing the normal section, from the vertical section obtained in the usual way, can easily be devised using the proportion of the cosine of the plane angle between vertical and normal planes.

FIELD MEETING IN THE PULBOROUGH DISTRICT, SUSSEX.

June 23rd, 1945.

Report by the Director : A. J. Bull

(Weald Research Committee Meeting).

THE Pulborough area was last visited by the Association in 1935 and 1939 [**1***] [**2**]. The route followed on this latest visit was planned to combine in one day the best parts of the two previous Field Meetings, both from a geological and a scenic aspect. Squadron-Leader J. F. Kirkaldy, who had hoped to act as Director, was unable to return from Germany, so the writer acted in his stead.

From Pulborough Station the party of 18 followed the main Horsham-Bognor road and noted that in the road cutting below the church the upper part of the Sandgate Beds was composed of Marehill Clay resting on Pulborough Sandrock.

Turning eastwards, to the bridleway along the crest of the escarpment formed by the Pulborough Sandrock, a fine view of the country stretching southward to the South Downs was obtained. Particular features of interest which were pointed out were the gullies in the scarp face of the Downs, the position of the gap cut by the River Arun, and the effects on the landscape of the Green hurst Anticline and the complementary Wigginholt Syncline, whilst the opportunity was taken to give an account of the stratigraphy of the Lower Greensand of the area [**3**].

The main road was regained and followed northwards to Codmore Hill, where lunch was taken. The roadside cuttings showed doggers of sandy limestone set in loamy sand belonging either to the Bargate Beds or the upper part of the Hythe Beds, which cannot be differentiated on the east side of the River Arun.

From Codmore Hill a road was taken leading westwards along the strike, and at Hill Farm exposures were seen in the stone bands near the base of the Hythe Beds. It was seen that these stone bands formed the crest of the escarpment, the lower part of which was clay. At Pythingdean, where the road forks northwards, disturbed beds of Hythe stone dipping steeply south and south-west and resting on Weald Clay were pointed out. It was suggested that these inclined beds were due to slip down the escarpment and not to a structural cause, as was suggested long ago by P. I. Martin [**4**]. The greater height and northward projection of the Lower Greensand escarpment on the western side of the Arun valley as compared with its behaviour on the ground already traversed, was explained as being partly due to a slight northward increase in thickness of the Hythe Beds [**5**], but mainly to a considerable development of chert in the upper part of these beds.

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* For List of References see p. 162.

The river was crossed at Pallingham Quay, where the abandoned Arun-Wey canal was seen to be built against the face of the low terrace which bounds the curious trench of the Arun-Rother river system [**6**].

The higher escarpment on the west side of the river consists of Weald Clay capped by Hythe Beds, and this was ascended by muddy paths through the woods. On the bridleway through the Quells, going down to Harwoods Green, it was interesting to note that the path was crossed by outcrops of stone beds apparently dipping into the hill. These very probably represent old landslips ; such slips are often on an arcuate clay sole, so that as the slipped mass travels downhill, the dip becomes progresisvely steeper towards the hill. After leaving the tongue of Weald Clay at Harwoods Green, pleasant woodland paths were followed up the face of the scarp to the chert beds above Brownshall Farm [**1**, Plate 15]. Further old workings in the chert beds were passed when traversing a track leading westwards through the woods. When the road was reached, a turn was made southwards past a good road section at Stretch Hill in the loamy lower member of the Sandgate Beds. Beyond Fittleworth the magnificent view point of Hesworth Common was ascended. Fortunately visibility was excellent, and the view of the Rother Valley with its background of the South Downs was greatly admired. The Downs could be seen from Butser in the west past Chanctonbury Ring to Wolstonbury in the east. After some time had been spent in describing and discussing the features of the view the party adjourned to the Swan Hotel at Lower Fittleworth for tea, during which a vote of thanks to the Director was proposed by Dr. Emily Dix.

After tea pleasant lanes were followed to Stopham Bridge, and several roadside sections in Folkestone Sands were noted with their characteristic current bedding and ironstone formation. Park Mound was then ascended ; this was the last good view point to be visited during the day, and in Park Lane the fossiliferous ironstone in the middle part of the Sandgate Beds was examined, though unfortunately no ammonite was found.

Pulborough Station was reached in good time for the return train.

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Arun Gap above Stopham.

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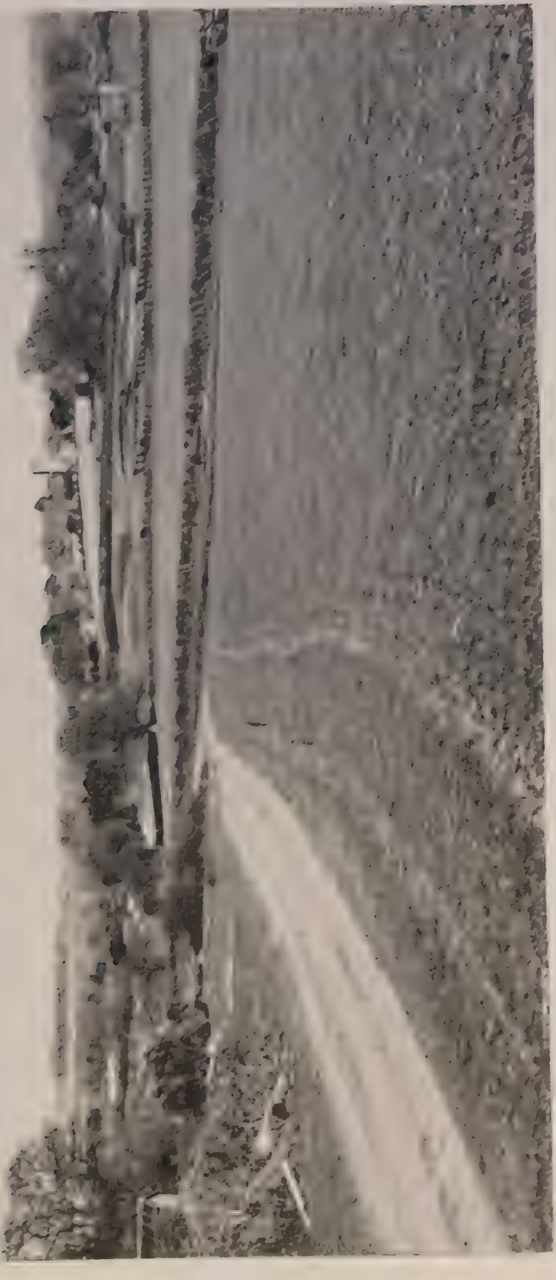

VIEW EASTWARD OVER PULBOROUGH.

[*To face p.* 162.

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EXPLANATION OF PLATES 13 AND 14

Plate 13.—Looking eastwards across the north end of the gap eroded by the River Arun in the Lower Greensand above Stopham. The view is from The Quells on the west side of the gap ; where the escarpment projects more to the north than it does on the east side of the river ; so that the view shows the northward facing escarpment, which here has a capping of stone in the lower Hythe Beds, and much of the slope is clay.

Plate 14.—The view from Park Mound eastward over Pulborough. The church stands on the northward facing escarpment formed by the Pulborough Sand Rock in the upper part of the Sandgate Beds.

FIELD MEETING AT READING

Saturday, May 4th, 1946

Report by the Director : Prof. H. L. Hawkins, D.Sc., F.R.S., F.G.S.

PART 1.

ITINERARY

A PARTY of about 60 members and friends attended this field meeting, and in brilliant weather a procession of cars headed by a double-decker Corporation bus conveyed it to and from the various brick-works in the County Borough. Unfortunately the late arrival of the London train made necessary some curtailment of the original programme.

The purpose of the meeting was to investigate the characters of the Reading Beds as now exposed in their type-locality. In this report an account of the places visited is followed by a summary of the comments on the phenomena seen made by the Director during the course of the afternoon.

Leaving Reading Station shortly before 3 p.m., the party crossed the Thames by Reading Bridge, and drove up the steep hill of the Peppard Road to Emmer Green. The prominent shelf formed by the Taplow Terrace gravel near Queen Anne's School was noted in passing ; and from the equally flat hill-top near Surley Row (a part of the 130-ft. plateau) wide views over Reading and the surrounding district were obtained.

The first stop was at the now-disused Caversham Brick Works, dug into an outlier of Tertiaries lying about 300 ft. above sea-level. The workings, although of no great depth, expose the Chalk, the Reading Beds and a considerable part of the London Clay. On the Survey Map (Sheet 268) the juxtaposition of these three formations is explained by faulting, but there are difficulties in accepting that interpretation. The Chalk, which represents the base of the subzone of *Conulus albogalerus*, is seen in a pit at the entrance to the main workings. The " bull-head " base of the Reading Beds rests on a perfectly even plane cut in the Chalk, below which borings filled with green sand extend to a depth of about a foot. Oysters and sharks' teeth occur sporadically in the glauconitic sands. The main clay-section is now partly obscured by slumping, but formerly it was possible to see a layer of lignitic peat about five feet above the Chalk. Above this peat-bed the entire visible succession of the Reading Beds (some 30-40 feet) consists of clay, which is mainly grey and silty below and brightly mottled above. These clays are to be seen only in the western part of the pit-face. Almost bisecting the workings, the indurated basement-bed of the London Clay cuts across the Reading Beds in a north-south line, dipping at about 40 degrees to the east. It is crowded with the usual fossils, as is also the almost black clay immediately overlying it. The eastern face of the pit (much obscured now by slumped gravel) consists of ordinary London Clay, with large septaria full of *Pinna* and *Modiola*. In so far as the face of the pit is considered, the oncoming of the London Clay might be explained by a fault hading eastwards at 40 degrees and coinciding with the base of the London Clay. But when the conditions on the floor of the pit are taken into account, the problem becomes much more difficult. Pitting and augering on the floor of the eastern part has proved that the Chalk and Reading " Bottom Bed " extend undisturbed beneath it at precisely the same level that they occupy in the western part, and that true London Clay (*not* its basement-bed) rests directly on the glauconitic " bull-head." Moreover, underground galleries in the Chalk, made long ago for the extraction of whiting, show no disturbances, although they cross and recross the apparent line of faulting. The dislocation of the London Clay is thus evidently superficial, but how it was brought about has yet to be explained. Only the lower part of the Reading Beds is seen at Emmer Green, and it proves to consist almost wholly of clay. In the district it is usual to find that the lower half of the series is mainly sandy, while the upper part consists of mottled clay. So far as this exposure goes, it proves as anomalous in the constitution of the strata as in their tectonics.

From the north-eastern corner of the County Borough the party crossed the town to the western side, and entered the " Tilehurst Pit " of the Grovelands Pottery. This pit is about three-quarters of a mile from the works, to which it is connected by an aerial cable. The extensive working here is almost entirely in clay. Beneath a thin cover of gravel there is a decalcified remnant of the London Clay basement ; all of the rest of the material exposed (some 50 feet all told) is either grey silty loam or vividly coloured mottled clay. Here and there thin and impersistent " channels-ful " of sand, or even of grit, are sometimes cut through. The clay just below the London Basement is very stiff, and maroon-coloured, for a thickness of about four feet ; this is very characteristic for the district, especially in southern and south-eastern parts of the town. Below this comes a grey and rather silty clay resting on brilliantly red and blue mottled clay. In the eastern part of the workings this is underlain by more grey silts, but towards the west it expands to occupy the whole of the main excavation.

The mottling is by no means haphazard. When seen in vertical section it reveals more or less regular streaks of vivid red perpendicular to the indistinct bedding at an average distance of 4 to 5 inches apart, penetrating the otherwise blue-grey clay. When seen in plan the red streaks are found to intersect the blue " matrix " in a roughly polygonal pattern in which hexagonal outlines predominate.

This feature was well displayed on a wide, gently inclined surface made by a mechanical excavator. This surface had dried in the hot sunshine, and had cracked into polygonal patterns comparable, but not coincident, with the red streaks. The redness is due to a concentration of haematite, partly as a stain and partly in minute pellets ; the blueness (greying when dry) of the bulk of the clay is presumably due to some less highly oxidised compound of iron. Some discussion took place as to the significance and origin of this strange colour-scheme ; the Director's suggestion as to its meaning will be found in the second part of this report.

On leaving this clay-pit the party followed the line of the aerial cable through delightful copses floored with wild hyacinths and ringing with the song of many nightingales, a real example of *rus in urbe*. A little more than half a mile of this pleasant walking ended in the " Norcot Pit " of the Grovelands Pottery. Here a really magnificent section, about 50 feet deep, shows London Clay, its Basement Bed, and some 35 feet of the Reading Beds. The top of the exposure is difficult of access, but blocks of indurated sandstone fallen to the floor yielded a rich haul of fossils, and other foundered masses of the London Clay were easily matched by their colour with their parent beds. Below the somewhat sandy lower part of the London Clay proper is a rich brown sand crammed with shells and locally indurated. This bed, about 2 feet thick, rests on an almost black clay of about twice the thickness. This clay, which is shaly, dries to a dull grey ; some of its bedding planes are blackened by obscure plant-remains, others are whitened by comminuted shells, and clusters of *Ditrupa* are frequent. A yellowish clayey sand, still richly fossiliferous, underlies the black shale, and rests with a clean-cut junction on the Reading Beds. This plane, and the sudden and complete absence of fossils, alone distinguish the two formations, for the topmost part of the Reading Beds is a yellowish-grey loamy clay, even at the top, but exceedingly uneven below. In one part of the pit this clay fills an obvious channel about 12 feet deep ; in other parts its thickness is a matter of inches. The bulk of the face of the pit consists of yellowish sand, intensely current-bedded at steep angles, and often suggesting the outlines of dunes. Irregular seams of pale pipe-clay, an inch or less in thickness, occur here and there, some of the more persistent ones often truncating the current-bedding of the sands beneath them. Many of the " planes " of current-bedding are littered with lines of small pellets, and even angular flakes, of precisely similar clay. In the floor of the pit a small hole shows about three feet of beautiful silver-sand, not bottomed. No water stands in the pit, so that it must be assumed that sand continues downwards to a considerable depth.

The striking contrast between the materials seen in these two pits, scarcely more than half a mile apart, is impressive ; for with the Basement Bed of the London Clay as a fixed horizon there can be no doubt that the upper half of the Reading Beds is exposed in both. In the Tilehurst Pit this is all clay, and in the Norcot Pit practically all sand. But in reality the contrast is more startling, for the Norcot Pit was opened as a clay-pit, and became a sand-pit when worked back for about a hundred yards.

Only a promise that more and better fossils were waiting in the next exposure sufficed to induce some of the party to rejoin the motors, but eventually a move was made to the Prospect Park Brick-yard. This large excavation is worked in two tiers, the lower for sand and the upper for clay. The upper working has not been dug for more than six years, and was found to be badly "slumped." The top part of the section repeats in almost every detail the record of the lowest portion of the London Clay as seen in the Norcot Pit, and huge tabular masses of the hard "fossil-bed" lie about on the upper floor of the pit. It is noteworthy that the London Clay has slumped far more than the Reading Beds ; this feature was equally marked at Emmer Green, and indeed provides a menace to the foundations of buildings erected on it. Probably the loamy nature of the lower London Clay admits water into its substance, thus rendering it sloppy ; whereas water drains off the almost siltless Reading Clays as from a duck's back.

Although the main face of the Reading Beds is obscured by slips, the nature of these deposits is well seen on the south side of the pit, where there is no London Clay overburden. They consist of about 20 to 25 feet of brightly mottled clay, and this scarcely 200 yards south of the Norcot Pit, where the corresponding layers are almost pure sand. But in the lower tier at Prospect Park a splendid section of the sands was seen, the films of pipe-clay and vigorous current-bedding showing to great advantage in the afternoon sunshine. In the middle of the cutting a complete "anticline" of current-bedding, its summit truncated by a pipe-clay seam, attracted admiration. It was generally agreed that this feature could be properly described as a buried sand-dune.

The delay in starting, and the time spent in whipping-up enthusiastic fossil-collectors, made it impossible to visit the classic section at Waterloo Kiln. However, apart from its historic interest as the scene of Robert Plot's record of "Oyster-shells at Cat's Grove," and as the site from which, in the past, some of the most spectacular samples of the "leaf-bed" have been collected, this pit would not have revealed many novelties. In it some parts of the mottled clays, carmine, purple, green and maroon, and the silts, grey, silver, buff, gamboge and brown, vie with Alum Bay in their lurid colours ; but the succession is the normal one of clays above and sands below.

The party drove from Prospect Park to the University, where light refreshments were provided in the Buttery. After this interlude and the customary vote of thanks, the Director invited those who

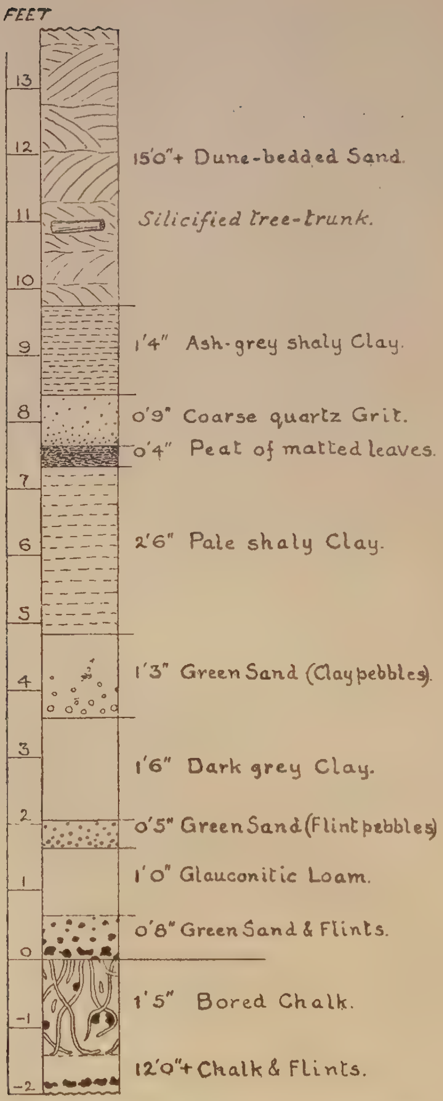

FIG. 26.—THE "BOTTOM-BED" OF THE READING BEDS AT THEALE.

could spare the time to visit the Museum of the Geological Department, where he demonstrated some features of the Reading Beds that had not been seen during the afternoon. The most noteworthy object was a series of fragments of a silicified tree-trunk recently found in the lower part of the Reading Sands at Theale. This log, 14 feet long and almost two feet in diameter (apparently part of a tree akin to *Magnolia*) was lying prone in the sand, and had been rotted to "touch-wood" before silicification. The heart of the trunk is riddled with borings made (presumably) by beetle-larvae, and on the outer surface are several of the round holes through which the mature insects emerged. There was no trace of bark, and the dead tree had evidently stood up stark and white until its final crash, the disturbance caused by its collapse being evident in the underlying sand. A detailed section of the succession from the Chalk to the level of the fallen log was exhibited, and is here reproduced (Fig. 26), since its record is typical of that of the "Bottom-Bed" in the Reading district.

PART II.

THE GENESIS OF THE READING BEDS NEAR READING

This section of the report contains a summary of the comments made by the Director at the various exposures visited, condensed into a more connected sequence than was possible when each pit claimed its own interpretation.

The stage began with a fairly rapid encroachment by the sea over the chalk floor of a denuded anticlinal vale. This sea must have come from the east, where it had already been responsible for the deposition of the Thanet Sands ; and its waves shaved off a level beach-platform that became riddled by borings. A shingle-beach developed on the platform, and was buried under glauconitic sand before most of the flints could be rounded into pebbles. Clusters of oysters grew here and there, but few other kinds of animals were indigenous ; perhaps the water was but brackish, or soured by "peat-juice" from the neighbouring jungle—almost certainly it was more or less land-locked.

Only four or five feet of marine sand and silt were deposited, but these sufficed to build up sand-banks and mud-flats that virtually "squeezed out" the sea, making swampy islets separated by muddy creeks. Jungle vegetation soon spread over many of these islets, and podzolised the clay on which it grew. In the innumerable meres the fine, pale silt was often littered with fallen leaves. So we find beds of lignitic peat (as at Emmer Green and Theale) on the sites of the island swamps, and the leaf-beds in pipe-clay (as at Katesgrove and Knowl Hill), where stagnant pools had been. In some places the patches of vegetation were absent, and there glauconitic loam slowly silted up the tidal creeks. The subsidence of the district was very slow, but the distance and low relief of the surrounding land permitted but little silt to reach the area, and many of the swampy islands became submerged. As a consequence, the course of the sluggish currents was changed and new islands grew near by ; there was little constancy in the distribution of swamps and creeks, either horizontally or vertically. Some few of the jungle-covered islands, such as the one represented by the podzolised shale nine feet up in the series at Theale, lasted long enough for large trees to grow ; others, devoid of vegetation, dried and cracked in the sunshine.

The conditions thus reconstructed, strikingly reminiscent of those that had long before produced the lower Coal Measures, prevailed over the district until some ten feet of deposits had accumulated over the chalk platform. This ten feet of strata (which may be less thick, but is rarely more) may be called the " Reading Bottom Bed " ; variable though the deposits may be they have a fundamental unity which can be defined as a marine invasion repelled by the spread of fens.

The remaining 65 feet or so of the Reading Beds show a comparable uniformity in diversity ; they represent an almost complete victory of land and fresh-water—the landward end of a delta instead of its seaward margin. The most frequent condition of this, the main part of the Reading Beds, is a two-fold division, with sands below and mottled clays above. The proportionate development of these two divisions is, however, extremely varied so that in some places almost the whole bulk consists of sand, in others of clay. It is unusual to find the order of the two types of deposit inverted, but they are apt to be intermingled near their junction.

The Reading Sands are always intensely and steeply current-bedded, and have both the form and the constitution of dunes. In the Theale section the choking of a jungle forest by the advancing dunes is dramatically shown by the beetle-ridden, bleached and rotted tree that crashed after the sand had begun to pile up around it ; but everywhere in the district the evidence of the sands is the same. In hollows between the dunes muddy films of pipe-clay collected in the puddles left by showers, and these films dried up and cracked into polygonal flakes that were caught up by gusts of wind and scattered over the dune-slopes. Sometimes short-lived lagoons spread sheets of pipe-clay over the low patches where dunes had been eroded.

Along certain belts the sand-dunes persisted almost throughout Reading Beds time, forming long, narrow ridges of dry ground across the marshes ; along others they drifted away to leave the swamps to cover their roots. At times a high wind might scatter a veneer of sand over stretches of marsh, or empower the water of a " broad " to wash out fine silt from its sandy shores, but for the most part the clay of the mud-flats was of ultimate fineness. When under water it was normally a blue-grey clay, unbedded in a uniform and sticky mass. When exposed to the air it dried and cracked, assuming a roughly columnar structure to a depth of a foot or more. The air "rusted" the iron salts to line the cracks with haematite. Later, when again submerged, the clay swelled and closed up these cracks, whose sides stuck so firmly together that only the red stains showed where they had been. Locally the whole exposed surface of a mud-flat became reddened to a depth of a few inches before a fresh inundation smothered it in grey silt.

Finally, when the combined thickness of dune-sand and fen-clay rose to about 80 feet above the Chalk floor, the "Oldhaven" Sea came flooding in from the east, carved off the uppermost five feet or so of the Reading Beds, to make a new plane of marine denudation for the support of the Basement Bed of the London Clay.

The Reading Beds are thus seen to represent, in their thickness of 75 feet, one complete cycle of geographical change. That the "Bottom-Bed" sea invaded the district from the east seems evident; it was merely an extension of the "Thanet Sands" sea. Moreover, in the southern part of the Hampshire Basin there is no trace of a marine "Bottom-Bed," and the south is the only other direction from which marine invasion could reasonably have been expected. Conversely, the silting out of this sea was equally obviously achieved from the west. Not only did marine conditions persist, albeit with many failures, in the Woolwich Beds, but the sands of the Reading Beds are replete with Tourmaline and sometimes yield pebbles of schorl-rock. These must surely have come from the south-west. Presumably the sand travelled by river for most of the distance, but the last stage of its journey may well have been by air.

It is interesting to compare the characters of the Reading Bottom Bed and the London Basement Bed. In the case of the former, the stones are practically all flints, and the great majority of these are subangular or unworn; they were evidently extracted from the Chalk near to their present resting places. In the case of the latter, flints are also predominant, but they are small and hammered into perfect pebbles; by then the Chalk was securely buried 75 feet down, and the nearest source of fresh flints will have been far away from the district. Faunally the two "invasion" beds are quite as dissimilar. Save for occasional sharks'-teeth, the fossils of the Reading Bottom-Bed are nearly all Oysters-molluscs which delight in estuarine mud-flats like those along the mouth of the modern Thames. The fauna of the London Basement Bed is, on the contrary, extremely rich and varied; oysters, though often present, are relatively scarce. But *Dosinia*, *Glycimeris*, *Natica* and *Ditrupa*, creatures of the shelving beach of an open sea, occur in rock-forming quantity, with a host of other shells. This was a more extensive invasion, and not until Bagshot times was it repelled.

FIELD MEETING AT GODSTONE, SURREY

(Weald Research Committee)

Saturday, 11th May, 1946

Report by the Director : A. J. Bull, Ph.D., F.G.S.

THIS field meeting was organised to take advantage of fresh workings in the Upper Greensand and the Folkestone Sand, which had been recently opened by Mr. Horace Fairall, of Godstone.

A party of 29 walked from Caterham Station up the Godstone road. At a convenient viewpoint in the col in the Chalk escarpment the question of the origin of the dry Chalk valleys so characteristic of both the North and South Downs was briefly discussed. Clement Reid in 1887 put forward the idea that they were formed under cold conditions ; when, with the Chalk saturated with water which was frozen and so rendered the rock impermeable, rivers would run on the surface. The correctness of this hypothesis had been confirmed during the exceptional freeze and thaw conditions of February, 1940, when Lord Kennet of the Dene had the unpleasant experience of an icy stream flowing through his house, which was situated at the bottom of a dry Chalk valley (*Nature* 23/3/40, p. 466 and 20/4/40, p. 629, *Proc. Geol. Assoc.*, 1942, liii, p. 139).

After this discussion the party proceeded to a new pit in the Upper Greensand near the south gate of Marden Park, which was being worked for hearthstone. The glauconitic sand was somewhat hard in places with a tendency to form nodules of chert. There were strings of calcite and also of powdered Chalk from the Scarp Drift above the pit.

The party then walked to Godstone Green, where an old pit in the Folkestone Sand had been re-opened. The sand showed the usual current bedding with foresets to the S.E. In places it is unusually free from iron staining, but near the top curly seams of limonite were forming which obscured the current bedding.

After tea at the Clayton Arms Hotel the sand pit in the Hythe Beds at Turner's Hill was visited. This shows a section of about 70 feet from the stone beds near the top down through the current-bedded sands almost to the lower stone beds, which are 10 feet below the floor of the pit. The pit was visited by the Association in 1935 and described by the late Frank Gossling the following year. A number of fossils mostly preserved in silica were collected.

The party returned to Godstone Green through Church Town, and noted in lane cuttings the clayey glauconitic Sandgate Beds and the pebbly base of the Folkestone Sands.

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SOME PHYSICAL FEATURES RELATED TO THE RIVER DEVELOPMENT IN THE DOLGELLEY DISTRICT

BY A. AUSTIN MILLER, D.Sc.

QUITE apart from the harmonious pattern of the broad waters of the estuary, the changing lights and shadows on the mountains and hills and the varied colour and texture of their cover of bracken, heather, grass and woods, the Mawddach valley owes much of its striking scenic quality to three events in its geological history :

1. Its successive rejuvenations in pre-glacial times ;
2. Its occupation by a considerable valley glacier, and
3. The recent submergence that has converted it into a tidal estuary.

It is proposed to concentrate on these three events and their consequences rather than to attempt a comprehensive account of the evolution of relief or a full description of all the scenic features of a valley which presents one of the most varied as well as the most beautiful landscapes in these islands. For other aspects the reader will turn to the account given by Professor Cox and Dr. Wells, prepared for the visit of the Association in Easter 1927 [**4***, especially pp. 311–317].

DRAINAGE PATTERN—ADJUSTMENT TO STRUCTURE

Mr. Lake [**1**] has suggested that the drainage of this region is part of an initially radial system developed from a centre " in the high ground near the source of the Conway," and has further shown that subsequent development stages have been strongly influenced by lines of weakness, due mainly to faulting, which have called into existence reaches which, in our region, all trend in a N.E. to S.W. direction. On the nature and distribution of the surface on which this drainage pattern developed he did not commit himself.

The well-known 2,000-foot platform of mid-Wales is excellently developed to the S.E. of the Bala-Tal-y-llyn-Towyn line and dominates the view in that direction from the summit of Cader Idris. Probably, too, it is represented on the shoulders of Cader itself, and on the summit of Y Garn and the long ridge of Llawllech running from Diphwys towards Barmouth. It is tempting to refer the initial drainage to that surface, and the great number of wind-gaps offers opportunity for endless speculation on the subsequent stages of evolution by capture. But I shall resist the temptation and

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* For List of References see p. 203.

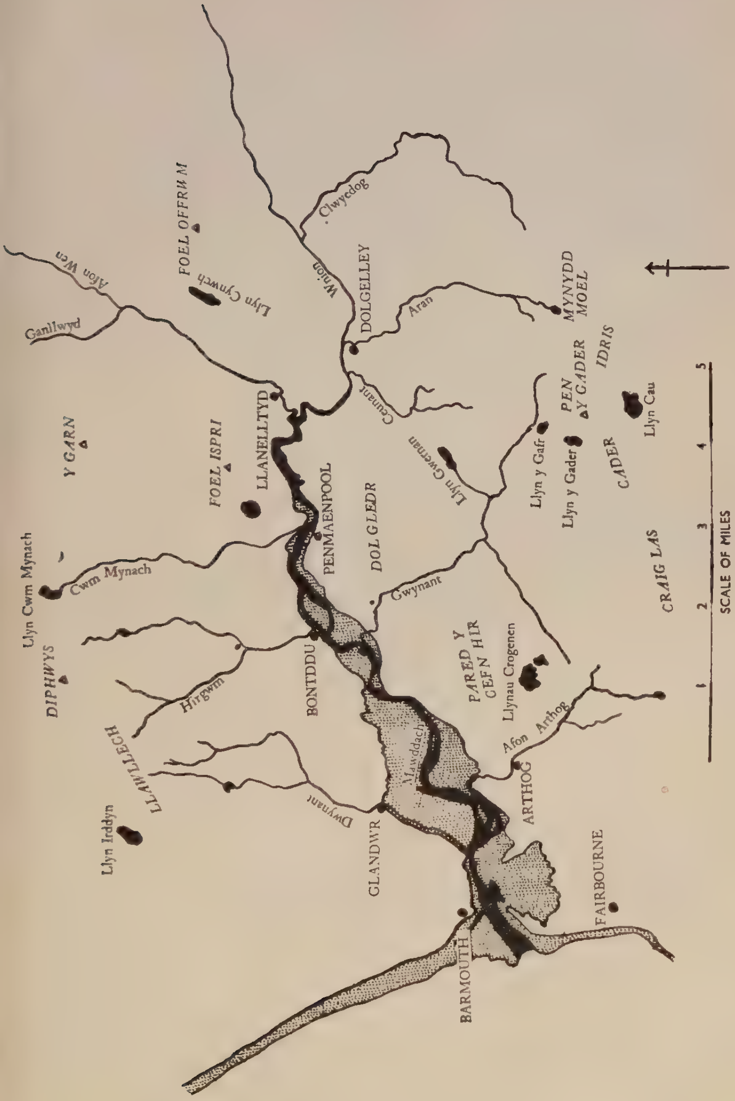

FIG. 27.—THE MAWDDACH AND MAIN TRIBUTARIES.

content myself with saying that the evolution of drainage has proceeded to such a stage that adaptation to structure has been largely or completely achieved by all the major streams. There has been a number of erosion cycles, probably at least four, and such captures as were not effected in the early ones have been completed in the next. In consequence the drainage has come to be dominated by major subsequents following the strike of soft rocks or fault lines. These receive short tributaries, generally at right angles, whose humble function is to drain the interfluve areas. With the possible exception of the Ganllwyd (upper Mawddach) valley down to the confluence of the Afon Wen at Gelli Gemlyn, none is of sufficient size and importance to be regarded as a surviving initial consequent stream.

The Bala fault, together with one of its branches—the Ceunant Fault—guides the Wnion nearly to Dolgelley and thereafter controls successively the upper Ceunant, the Llyn Gwernan hollow and the Upper Gwynant valley. Another fault guides the stream followed by the Cader Idris Road from Rhŷd Wen down to Dolgelley. The Derwas fault governs the great trough of the Ganllwyd valley beneath Precipice Walk, also its continuation upstream, the valley of the Afon Wen. These and many other examples of fault control have been described by Professor Cox and Dr. Wells in their various publications on the district [**2, 3, 4, 5**].

It is noticeable and important that below Dolgelley the direction of the Wnion Valley is not controlled by faults but by the strike of the relatively softer Upper Cambrian Beds. Here for a short distance (about four miles) the general Caledonian (N.E.–S.W.) strike swings round to an E.-W. direction and the valley does the same, until at Penmaenpool the Caledonian trend regains control, and the river, now the Mawddach Estuary, obediently follows. The structual significance of the change of strike and the escape from fault control have been discussed by Cox and Wells [**2**, pp. 312–315], who draw attention to the parallel case of the Dovey valley, 15 miles to the south, and point out that "it is probably more than a coincidence that in each case the only important town of the valley—Dolgelley in the one case, Machynlleth in the other—should stand just at the point where the valley leaves the fault line." Primarily, of course, these are bridge towns situated at the lowest convenient crossing point in former times; this was naturally near the tidal head where the estuary narrows down and firm ground is found on both banks.

Two further examples among the many which can be traced may be mentioned. One is provided by the Menevian (Clogau Beds) whose outcrop runs parallel with but about one mile N.W. of the estuary. Where the outcrop of these shaly beds crosses hill-spurs there is always a down-sag or a flattened reach and where the streams descending from the rough upland area of the Harlech grits on Diphwys and Llawllech cross this band their valleys undergo a marked change, becoming wider and more open. In such places the slopes are gentler and there is more good pasture and cultivation, contrasting strongly with the craggy ground and rough pasture of the rocks above and below.

The second is provided by the granophyre of the Crogenen sill, which owing to its intricate small-scale jointing, functions, rather unexpectedly, as a weak band. Being 1,200 feet in thickness and further increased in width of outcrop by strike faulting it makes a wide belt of relatively low land (generally below the 700-feet contour) extending from Tal-y-Waen to the Crogenen lakes, separating the high ridges of Pared y Cefn Hir and Dolgledr to the north-west from the hills of Mynydd Caer Go and Gelli Llwyd to the south-east. It has been picked out by subsequent tributaries of the Afon Gwynant which enter near Kings, where the outcrop of the sill crosses the Gwynant valley. The Crogenen lakes occupy the western end of the hollow due to the granophyre.

THE REJUVENATIONS—VALLEY PROFILES

The clearest evidence of rejuvenation is presented by the form of the many tributary valleys which drain into the Mawddach. In their middle reaches these streams tend to occupy moderately open valleys, falling fairly steeply but without marked irregularities such as waterals until a point, usually about a mile above their confluence with the Mawddach. Here they plunge steeply over a number of picturesque falls in steep-sided ravines down to the level of the main river. At first sight these features might seem to be due to glaciation, and the valleys might be classified as hanging valleys ; but there are at least three objections to this view : 1, the nick point is too far upstream to have migrated such a distance in post-glacial times ; in the Gwynant valley, for instance, it is two miles from the confluence ; 2, they are pre-glacial in age and glacial deposits occur within the rejuvenated ravine sections ; 3, they are not related to phenomena of glacial over-deepening, but are, on the other hand, clearly related to former pre-rejuvenation levels which are determined as such from other evidence. This evidence is detailed later.

Some of the valleys show two stages of rejuvenation. The Afon Gwynant, for example, is a turbulent torrent in a steep-sided gorge above Pont Abergwynant. A quarter of a mile farther upstream a shelf with a base level just above the 200-feet contour appears above the eastern bank of the river, which is here flowing in a ravine, river level being about 80 feet below the shelf. The shelf is occupied by gently sloping meadows and has been utilised as a site for a school.

This shelf is best developed across the outcrop of the less resistant Dolgelley Beds (in the upper part of the Lingula Flag group). Farther south, i.e. up the valley, the shelf narrows and disappears where the valley is crossed by the outcrop of the more resistant Niobe Beds of the Tremadoc group, which form steep scarps on either side of the valley. In this direction the stream bed rises and attains the significant 200-feet level at a nick point near Pont Ty-gwyn, and this approximate level is continued along the upstream course of the river to a point above Kings, where meadows fringe the bank. This part of the valley may indicate a former upstream extension of the 200-feet base level. But it is possibly significant that the nick point at Pont Ty-gwyn occurs just where a dolerite sill crosses the stream and the narrow strip of meadows at Kings is situated immediately above the point where another band of dolerite crosses the stream.

These hard rocks naturally resist erosion by the stream and consequently create and perpetuate nick points. The occurrence of these points approximately at the 200-feet level may therefore be fortuitous and not necessarily connected directly with a former extension of the 200-feet platform. The question of how far the 200-feet shelf extended upstream is not, however, of great importance, since the evidence for a bench at 200-feet on the valley side farther downstream (by the school) is sufficiently clear.

Beyond Kings the road up the valley now begins to climb steeply until above Cefn-yr-Owen-Isaf it attains a higher flat shelf at 500 feet, into which the Gwynant is steeply entrenched at Capel Peniel. Both longitudinal section and cross-section thus exemplify two separate rejuvenations, dissecting graded surfaces which suggest correlation with base-levels at about 200 feet and 450 feet respectively. These features are at least in part independent of the strike of the beds ; in fact, the section in the river provides a series of exposures of beds ranging from Ffestiniog and Dolgelley divisions of the Lingula Flags, through the Tremadoc Series into the Arenig Series, as well as a number of intrusions.

The profiles of this and other valleys would repay careful levelling to discover the exact position and height of the nick points. The contour interval on the Ordnance maps provides a framework of reference altogether too coarse for reliable conclusions to be drawn as to the base levels to which the valleys are graded (i.e. the heights of their former confluences). A rough examination suggests a major level between 350 feet and 450 feet, with indications of a 200-foot level in addition [**6**, p. 38].

In some cases the upstream migration of the lower nick point seems to have overtaken the upper one, so that only one break of slope occurs in the stream profile. This is so in the main Wnion valley, where the nick point occurs at 400 feet by Wnion Halt. The Dolgelley to Bala railway climbs out of the gorge by steep gradients of one in 50 on to the graded upper reach, which it then follows to the summit of the pass leading eastwards to the area drained by the Dee system.

VALLEY-SIDE FACETS

The other line of evidence is provided by step-like shelves which are preserved here and there at varying levels up the sides of the larger valleys. These features present peculiar difficulties in recognition, description and in definition, difficulties which are inherent in the nature of the country and inevitable in a region of steep slopes and youthful topography, which has never, in a long and eventful history, reached or passed a stage of early maturity ; certainly the peneplain stage has never been approached. Flat surfaces of considerable width are not, therefore, to be expected ; facets of gentler slope are the most that can be expected. Such facets are best preserved where the river, in process of lowering its valley, has swung from one side of the valley to the other, leaving its old valley floor and slopes, as it were, stranded on the new valley side. Although not terraces in the strict sense—no alluvium or gravel has been found on them—they may be compared to terraces in that they represent old valley floors and sides relict from an earlier and higher stage in the evolution of the valley. If this is their true mode of origin they will not be expected to lie all at one level throughout the length of the valley, since the base level of the facets should rise gradually upstream, as in fact they appear to do. Their real nature and significance, therefore, would be obscured if we referred to these old valley floors as " relicts of a 450-feet platform." It is permissible, however, to estimate the base level (at the seaward end of the main valley) to which they graded and to refer them, for example, to a " 450-foot stage," realising that a 450 stage in the Gwynant Valley may be represented at Dolgelley, three miles further inland, by a feature at 500 feet or even higher.

An alternative method of nomenclature is to avoid reference to particular levels and to christen each stage with a local place-name referring to localities where each is well developed. On this principle the lowest stage, graded to about 200 feet, may be called the " Ynys stage," from the numerous islands and knolls that preserve on their summits fresh or degraded records, and the next higher, graded to about 450 feet, as the " Rhŷd Wen stage," from the locality south of Dolgelley.

In addition to having a down-valley fall these facets must also have a slope towards the main river when viewed in cross section from along the line of the estuary. This slope will be in the form of a catenary curve rising from its inner edge, whose height is significantly related to the old river level, to heights of perhaps

300 or 400 feet greater away from the river, where it might appear to have no significant relationship to the old river level. And yet it is the same facet over all this range of altitude, characterised by a continuous catenary curve, concave upwards.

Such a facet, uplifted above the base level to which it was graded, must suffer destruction by the headward encroachment of a new facet graded to the new base level. The earlier facet thereby loses first its significant inner margin and, as it is devoured by headward erosion, becomes progressively more and more difficult to relate to its old base level. The junction between two such facets, new and old, is marked by a fairly well defined break of slope of convex form which slowly retires upstream and upslope. I have laboured this fairly obvious point because I have found that the only satisfactory method of analysing the relief of this steep polycyclic landscape is to map each individual facet and the physiographic breaks of slope that separate lower from higher facets.

It is, of course, necessary that facets and facet-contacts must be independent of geological structure and must be determined by erosion, though, as in the case of valley nick points, breaks of slope may survive long in their upslope migration in the neighbourhood of resistant rocks. Although most of the facets have been mapped over their full range I have indicated only the lower and flatter portions of each on the map reproduced here (Fig. 28).

A further serious difficulty in the recognition and mapping of the facets is the consequence of later glaciation. All were overridden by ice and have suffered much roughening by scour and plucking. In consequence they are much easier to detect in a distant view, for when seen thus a general impression of smoothness of the major features is obtained and the minor irregularities which confuse the observer on the spot become less prominent or even invisible. This applies particularly to features on the slopes of the main Mawddach valley, which was the valley occupied by the greatest thickness of active ice. In the tributary valleys the facets are much smoother, for the regolith is thicker and the bare bones of solid rock project less formidably. A veneer of drift often covers and obscures the solid geology, and smears of boulder clay sometimes give the appearance of a terrace that does not exist in the solid rock beneath. Precautions have been taken to ensure, as fully as possible, that the facets mapped are carved out of solid rock and of preglacial age.

The Ynys Stage (? 200 feet)

The lowest stage is represented in the estuary region by a number of wooded hills rising like islands through the estuary alluvium. Coed-y-Garth (Ffestiniog beds), Farchynys (Maentwrog beds), and Tyn-y-Graig (Ffestiniog beds), all rise just above 200 feet

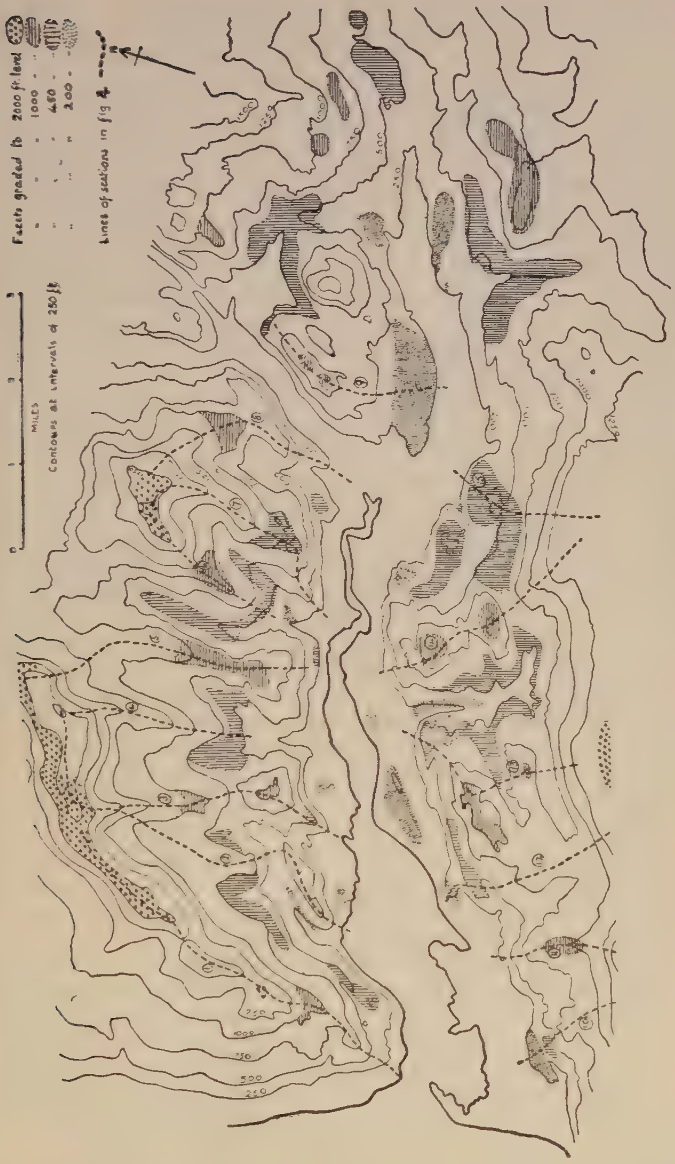
Facets graded to 2000 ft. level
" " " 1000 " "
" " " 480 " "
" " " 200 " "
Lines of sections in fig 4
N
0
1
2
3
MILES
Contours at intervals of 250 ft
1000
750
500
250

FIG. 28.—EROSION FACETS AND POSITION OF CREST-LINE SECTION.

Smaller ones such as Fegla Fawr (> 100 feet), Fegla Fach (> 50 feet) and the one near Glandwr (> 100 feet) have been considerably lowered by subsequent erosion and cannot be regarded as terminal surfaces. Some of these may be detected on the spur profiles in Fig. 30, where they are indicated by the symbol ooo. Traced up the estuary this 200-feet stage may be represented near Penmaenpool by the shelf at the " Kennels " behind Penmaen Uchaf, but the biggest development of a possibly corresponding surface is found on the north side of the Wnion valley in the area near Dolgelley. Here is a very considerable shelf, about one and a half miles long and nearly half a mile wide, at a height of about 300 feet. The feature slopes slightly to the north and it seems probable that the course of the Afon Wnion at this stage ran about three-quarters of a mile north of its present position and flowed from Ochryfoel by Pandy Bach to Hengwrt along a shallow depression which is now utilised by a third class road.

On the right bank of the Ganllwyd valley, about half a mile north of Llanelltyd is a spur between the main river, and a small tributary called the Afon Wnion (not to be confused with the Wnion that flows past Dolgelley) is bevelled at 300 feet. It is conspicuous in the view from Precipice Walk.

About two miles farther up the main Wnion valley on the south side above Bont Newydd station is another good development of this surface, which by this point has risen to about 350 feet O.D.

All of these bevelled spurs, shelves or " islands " (Ynys) have been over-ridden by the ice of the Mawddach glacier and have been re-shaped in the process. It is not to be expected, therefore, that they will show well-defined terminal surfaces. Their summits are generally rounded or undulating and are rendered still more difficult to recognise by the heavy covering of woods that generally clothes them to the top. But their general coincidence of level is striking and they show up most conspicuously in any view up or down the estuary, such as that from Panorama Walk. None of them is structurally determined, all are cut across the grain of steeply dipping rocks of varying age (Upper Cambrian and Ordovician, Pyroclastic group).

It will be seen that the downstream fall of this terrace from Bont Newydd to Barmouth is about 150 feet in about 10 miles. At first sight this seems similar to the present stream, which falls 170 feet in the same distance. But this is done in two strongly constrasted reaches. In the rejuvenated tract between Bont Newydd and Dolgelley the Wnion falls 130 feet in three miles, but from Dolgelley to Barmouth, where it is heavily aggraded in the drowned estuary reach, the fall is less than 50 feet in seven miles. Rock bottom at Barmouth, however, is probably about 100 feet below O.D. and the river bed, before the last cycle was interrupted by submergence and aggradation, had a steeper fall, because of its recent rejuvenation, than at the more mature 200 feet level.

The Rhŷd Wen Stage (? 450 feet)

The next stage, suggesting a sea-level of about 450 feet, is not well preserved below Penmaenpool, but is strongly suggested here by the open valleys above the nick points referred to above. The Glandwr, Gwynant, Bontddu and Cwm Mynach valleys all have nick points which are consistent with a former grading to this level. It is probably represented by the rough shelf at 500 feet east of the Panorama Walk at Llwyn On, cut across the steeply dipping Maentwrog beds. The next two spurs upstream from Ffridd Goetre Uchaf and Allt Boeth are strongly bevelled at 500-550 feet. Across the estuary the ridge south of Tyddyn Sieffre at 450-500 feet is cut across the Dolgelley and Tremadoc beds and is unaffected by the fault that crosses its northern end. Above the big abandoned quarry (Chwarel Tyn-y-coed) two miles to the N.E. is a wide shelf in Tremadoc Slates sloping gently down to 500 feet, where it is sharply cut off against the deep hollow (glacial channel, see p. 195) followed by the main road. Some of these may be detected on the spur profiles where they are indicated by the symbol xxx.

But the best monument to this stage is the wide shelf at about 500 feet to the south and west of Dolgelley crossed by the Cader Road between Rhŷd Wen and Llyn Gwernan. This area of uniform general height, rather roughened and obscured by glaciation, extends over an area about one and a half miles long and half a mile wide (see Fig. 29). The highest point is in the centre, where it exceeds 500 feet ; this may represent the core of an abandoned meander, for it is encircled by a clearly recognisable channel passing Rhŷd Wen, Gelli-llwyd and Tyn-y-llwyn. The depression is backed by the steep slopes rising to Dolgledr. Its eastern end is drained by two streams, one an unnamed stream, which is followed by the Cader Idris Road and enters the Wnion at Pandy-'r-Odin ; the second stream draining the depression is the Ceunant, whose higher valley sides overlook a rejuvenated ravine. Beyond the Ceunant valley the terrace feature can be traced along the south side of the Wnion valley to the Clwyedog valley, which it crosses just above the rejuvenation head at Pant-ar-Ddibyn, where the gorge of Torrent Walk begins. Beyond the Clwyedog it is still traceable and makes a fine terrace feature at 550 feet, on which stands Cefn-y-maes. The road south from Bont Newydd station presents a good illustration of the terrace staircase, rising to 350 feet, flattening at this level, rising steeply again to 550 feet, flattening out again where the road turns right and left along the 550-foot terrace. The back-face of the terrace rises steeply to Brithdir Isaf, over 1,000 feet. The 550-foot terrace may also be recognised on the north side of the Wnion valley opposite Wnion Halt. Here

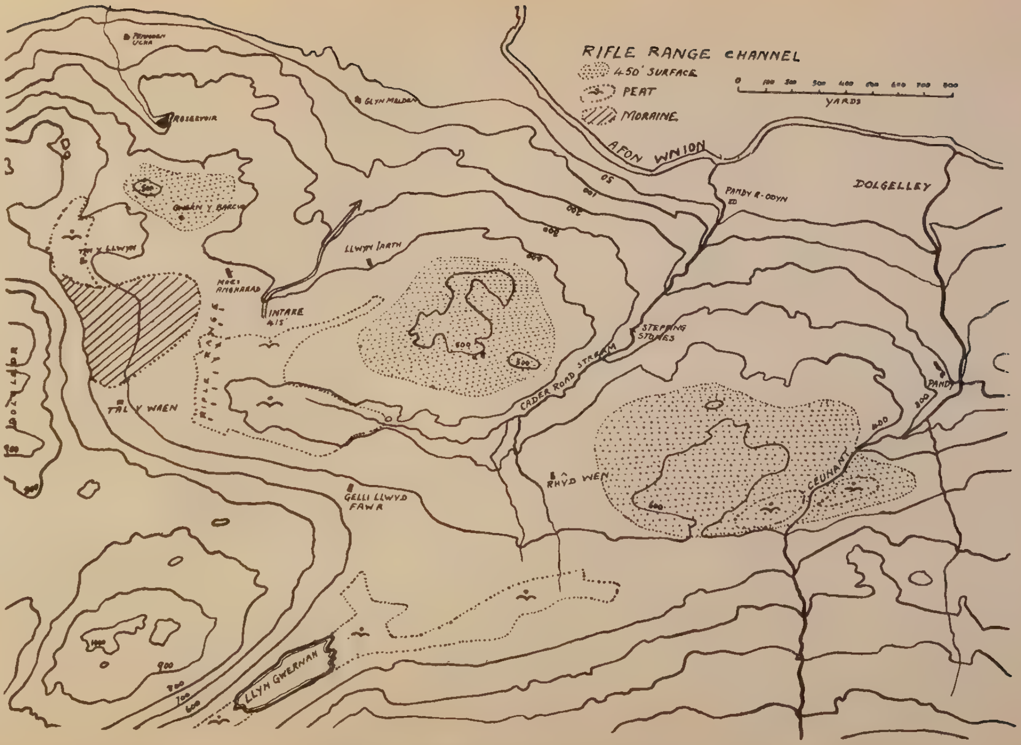

FIG. 29.—"RIFLE RANGE" CHANNEL.

wooded slopes rise steeply from the rejuvenated river, the land flattens and the woods give way to meadows and cultivation at 550 feet.

The downstream fall of this terrace, about 100 feet from Bont Newydd to Barmouth, seems less than that of the Ynys stage and suggests that the river had reached a more advanced stage of grading.

The Foel Ispri Stage (1,000 feet)

Any erosion surfaces higher than those just described are preserved only fragmentarily on spurs and ridges which enjoy some degree of immunity from destruction by later weathering and erosion. It is, however, suggestive that nearly all the spurs to the north of the estuary flatten to about 1,000 feet and then fall abruptly either to the estuary or to one of the lower erosion levels.

In order to demonstrate this feature I have drawn, in Fig. 30, a section down the crest-line of each spur, which is thus, as it were, pulled out straight and viewed from the side. The positions of these spur profiles are shown by the broken lines on Fig. 28. Placing these sections about the right distances apart, but pulling them forward or pushing them back until they are " dressed by the right," I have arranged them so that the outer edge of the probable 1,000-foot platform follows a line running obliquely backwards to an apparent vanishing point at the head of the estuary. Thus we are enabled to see " round the corners " and to get an idealised view up the estuary designed to show off the 1,000-foot platform to the best possible advantage. It should be realised that all sections are drawn to the same vertical and horizontal scale ; the view is therefore orthographic and not perspective, and there is no shrinkage towards a distant vanishing point in this respect.

The least satisfactory spur section is No. 4, running down from Diphwys to Hirgwm. The flat reach on this spur is about 200 feet too high for a 1,000-foot shelf. No. 2, from Llawllech to Garth, is a little too low. The bevelled portion of each of the north bank spurs is abruptly truncated at about 900 feet, below which the spur plunges abruptly towards the estuary. This feature, which is well shown by Nos. 1, 3, 5, 7 and 8, is partly due to glacial truncation (see p. 192).

The device described above works well for the north bank spurs which run in well defined ridges forming the divides between parallel tributary valleys, but the conditions on the south bank are very different. Here for reasons which are explained on pp. 188–192, the ridges and valleys run north-east and south-west, parallel with the estuary, and the widely spaced Arthog, Gwynant and Ceunant tributaries, bursting through these ridges, have not been able to shape the wide interfluve spaces between them into parallel divides. The sky-line profiles, therefore, as seen up the estuary, are like saw-toothed sections across ridge and valley. But the interesting

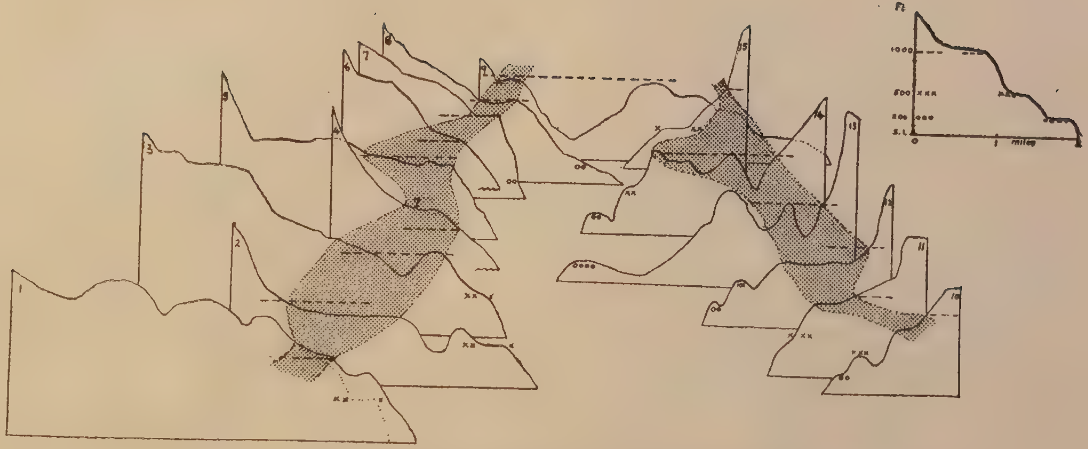

FIG. 30.—CREST-LINE PROFILES OF SPURS. For position of sections see Fig. 28. Stippled area shows reconstruction of 1,000-feet surface.

point about such profiles, drawn through the highest points, is that the ridges all rise to about 1,000 feet and that the height of the ground does not materially exceed this level until we reach the steep slopes up to Cader Idris and Mynydd-y-Gader. With the exception of the craggy summit of Bryn Brith (1,256 feet) there is no land above 1,011 feet in the two-mile-wide belt of country between Cader cliff and the estuary. If, therefore, we imagine an earlier Mawddach flowing at about 1,000 feet above the present level, here is a wide valley bottom for a very considerable river to flow over. Cox and Wells [**5**, p. 313] tentatively asked whether the river had ever followed the Gwernan-Ffordd Ddu depression and drew attention to " a strongly terraced feature which declines westward on the slopes of Cader Idris." They go on to say : " This feature, which is crossed by the Pony Track, is quite independent of the rocks that compose it and clearly marks a rejuvenation feature in an old high level valley which was graded to a base level of 1,100 feet to 900 feet." The left bank of this old valley stands out on the contour map as a steep slope down to the 1,000-foot contour, which can be traced on the west face of Mynydd-y-Gader, under the west shoulder of Cader (Craig Lâs) and over the divide at Ffordd Ddu beneath Craig Cwm Llwyd and Pen-y-Garn, to reach the sea at Friog.

The base level of the time cannot be fixed with any accuracy ; it was probably nearer 900 feet than 1,000 feet, but the higher, and rounder figure is a more convenient temporary notation.

As has been described above, this course had been abandoned by the date of the later (450-foot) stage ; the diversion probably occurred quite early in the rejuvenation that led to the dissection of the 1,000-foot surface.

The 2,000-Foot Platform

All other erosion features are dwarfed in magnitude by the 2,000-foot plateau, so conspicuous farther east and south. From the summit of Cader or from Craig-y-Ffynnion this stretches away to the south-eastern horizon, forming the summit of a number of flat-topped mountains and ridges. In the Mawddach region it may be represented by the long ridges of Llawllech, the long west shoulder of Cader and by the summit of Y Garn. Above this surface Cader, Diphwys and the Rhinogs rise as monadnocks.

INTERPRETATION OF THE EROSION FEATURES

The 2,000-foot surface of Mid-Wales is an accepted erosion surface, though opinions differ on its origin. But the lower levels, at 1,000 feet, 450 feet and 200 feet, have not hitherto been described and some justification is demanded for postulating their existence. Some of the evidence has been described above ; there remains the task of interpreting the observations.

If the dissection of the 2,000-foot surface had been accomplished in a single erosional cycle there would doubtless be chance irregularities of slope, with flatter facets, generally on softer rock. Migrations of the stream bed, too, would leave steep slopes (banks) and gentle (floors). But had the downcutting been continuous these facets would occur indiscriminately at any height, as do the unpaired terraces produced by the destruction of its flood plain by the shifting meanders of an old river. This is not the case, and the facets appear to fall into three series, the lower two at least rising gently in height when traced upstream. The thalweg of the river, at each of the two later stages, was only half to two-thirds as steep as that of the present stream, when allowance is made for the flattening, by drowning, of the estuary. When carried to the present river mouth the two stages appear to be graded to sea-levels of about 200 feet and 400 feet to 450 feet respectively, and the profiles of the rejuvenated tributaries concur, broadly, in this conclusion.

This suggests two periods of fairly prolonged still-stand in a rising area ; or alternatively of a falling sea-level.

The picture thus presented is simple—too simple, for neither the river profiles nor the erosion terraces can be fitted quite tidily into so precise a scheme. Some of the tributary profiles are directed to heights above, below or intermediate between the two preponderating levels. And some erosion facets are out of agreement ; for example, the wide flat with no structural cause that occurs at 400 feet, half a mile N.W. of Llanelltyd, on which stands Llyn Tan-y-raig. Such features must have been produced during the period of relatively rapid down-cutting before, between or after the major still-stands. The conclusion must be that the still-stands are only temporary checks, or periods of a slower rate of change, in a continuous fall of sea-level.

THE EVOLUTION OF THE DRAINAGE

I do not propose to go any further back in time than the 1,000-foot stage, at which time most of the hill tops probably preserved relics of the 2,000-foot platform, so that the amplitude of relief, between valley floor and hill top (apart from monadnocks), was about 1,000 feet ; less than it has ever been since and about half of what it is today. Peneplanation was more nearly approached than at any subsequent time; and the width of the belt that includes fragments of the 1,000-foot stage on hill and spurs is about four miles. (See Figs. 28 and 30.)

It has been suggested above that the main channel at this time followed a line from Dolgelley, by the Llyn Gwernan—Hafotty Fach—Ffordd Ddu hollow to the coast at Friog. If this were so the main river has since been displaced to a parallel line, that of the present Mawddach estuary, some two miles farther north of the original line. There is evidence that this displacement has been brought about by a series of captures effected by a powerful subsequent developing parallel to the Gwernan hollow along the line of the estuary. The energy that was required was provided by the uplift of the land (or the fall of the level of the sea) that brought about the dissection of the 1,000-foot level.

It is a striking fact, for which no explanation is found in the geology, that the left and right bank tributaries of the Mawddach enter opposite each other (the Arthog stream is in line with the Glandwr, the Gwynant with the Bontddu). It is further noticeable, from the higher contours, that both the Arthog and the Gwynant valleys are funnel-shaped, narrowing downstream to spout-like necks at their present confluences with the Mawddach. It is easy, then, to imagine the Glandwr (some 1,000 feet above its present bed) flowing across the present estuary and up the Arthog valley to a confluence at Hafotty Fach ; and the Bontddu streams flowing up the Gwynant valley to a confluence near Dyffrydan (Fig. 31, 1).

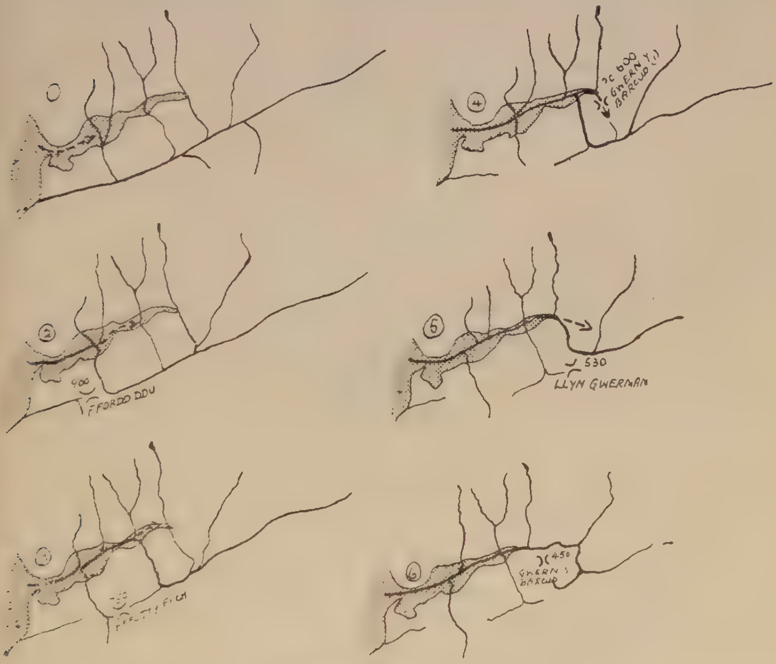

FIG. 31.—PROBABLE SEQUENCE OF CAPTURES.

The long Cwm Mynach valley, however, is faced by no opposite tributary entering the Mawddach from the south near Penmaenpool. But there is a wide valley, capacious enough to carry all the waters of the Cwm Mynach, falling southwards from Tyn-y-llwyn to Rhŷd Wen and formerly probably continuous with the Ceunant. Its flat floor is about a mile wide and is occupied by a peaty swamp partly of glacial origin across which is an old rifle range. Down this depression we might think to lead the Cwm Mynach before capture. But unfortunately there would be no way out for this water, since the rifle range valley is clearly continuous down to 400 feet, but the col at Llyn Gwernan, the only alternative outlet, is above 500 feet. It is, therefore, clear that the lower part of the rifle range valley was cut after the Wnion had been diverted to its present course by the last great capture at Dr. Williams's School, just west of Dolgelley. It is probable, however, that the waters of the Cwm Mynach did follow this line, but at a higher level (above 500 ft.).

Each capture occurs in two stages, the first being the bisection of the southward flowing consequent by the encroaching subsequent. The beheaded portion then had its drainage progressively reversed by the development of a new obsequent whose headward encroachment finally reached and diverted the original subsequent stream flowing at the higher level, whose beheaded lower end then took its rise in a wind gap. The succession of captures and the heights at which they occurred can be reconstructed from the wind gaps whose abandonment they have caused.

The stages are as follows (see Fig. 31) :—

(1) Initial drainage ; subsequent undermining the middle reaches of the Glandwr-Arthog consequent.

(2) Capture by Arthog river. The spur at Ffordd Ddu is severed by a dry gap just below 900 feet, but this is too small to be the wind gap of the original channel which was probably above 900 feet. The capture was thus effected very early in the rejuvenation that followed from the uplift of the 1,000-foot stage.

(3) Capture by the Gwynant. The col at Hafotty Fach is at 791 feet, but contains some drift. The solid floor may be about 750 feet, which would be the level at which the waters were turned down the Gwynant valley, which is very wide at this height.

(4) Capture of the Upper Cwm Mynach (see Fig. 29). The encroachment of the subsequent (Mawddach) diverted this stream at Penmaenpool, leaving rather less than half the river rising in a wind gap near Penmaen Ucha. An obsequent stream developed and displaced the watershed southwards to near Gwern-y-Barcud, but it is possible that before the course could be

completely reversed the next, and most important, capture occurred. The process, therefore, may not have proceeded to the logical conclusion of the previous two, and the Wnion drainage must have continued for some time to escape by the Llyn Gwernan channel whose level is about 530 feet (though there is much drift on the floor) until, finally,

(5) the powerful subsequent, the Mawddach, now encroaching eastwards as the strike swings round between Penmaenpool and Dolgelley, captured the Ganllwyd valley and went on to

(6) capture the Wnion upstream from Dolgelley, thus completing the present pattern of drainage.

The chronological sequence of these last captures is rather uncertain. The Gwernan col must have been abandoned at about 500 feet, i.e. about the end of the cycle that resulted in the 450-foot erosion surfaces elsewhere. The divide at Gwern-y-Barcud is now below 500 feet and is not a wind gap, its eastern side being entirely missing and replaced by a wide development of the 450-foot erosion surface. Did the lowering of the Gwern-y-Barcud col cause the abandonment of the Gwernan outlet? It is difficult to give an answer because (1) of the unknown thickness of drift in the cols and (2) the incalculable amount of subsequent lowering and reshaping by both sub-aerial weathering and glaciation. But the wide and almost continuous development of the 450-foot surface from the shelves above the rejuvenation in the Clwyedog valley and the Ceunant valley, past Rhŷd Wen and Llwyn Iarth to Gwern-y-Barcud suggests that a large river went this way (see Figs. 28 and 29). I regard this as the former course of the Wnion flowing in a large curve nearly a mile south of its present course. The wide, smooth curve of the steep slope that rises above Gelli-Llwyd and Tyn-y-Llwyn to the heights of Dolgledr has the appearance of being the left bank of this river, and the low hills, shown by the closed 500-foot contour, have the appearance of a meander core. Since, however, these hills are composed of igneous rocks, dolerites and porphyrites, which under any form of sub-aerial erosion would offer greater resistance to denudation than the surrounding slatey rocks, any resemblance to a meander core may be entirely fortuitous. The river bed would lie on the site of the great Rifle Range flat channel, but, of course, at a greater height (about 450 feet) and falling in the opposite direction. It cannot be responsible for the present form of that channel, which actually appears to be graded to the 200-foot level, falling gently to the stepping stones near Tai Newyddion, where the rejuvenation begins abruptly and unmistakeably.

It remains to account for the northward shift of the Wnion to the present course at Dolgelley. This was probably the result of the final capture by the powerful subsequent (stage 6 above) and was encouraged and aided by the rejuvenation that led to the dissection of the 450-foot stage and finally to the re-grading at 200 feet.

By this stage adjustment to structure was fairly complete and no further significant changes of course have taken place apart from those due to glaciation described below.

GLACIATION

Although the Cader Idris mass acted as a centre of dispersal and had its own system of small glaciers, which have given it the magnificent corries of Llyn-y-Gader, Llyn Cau, etc., the general direction of regional ice-movement was from N.N.E. to S.S.W., i.e. following the prevailing direction of the subsequent (strike) drainage lines. The best glacial U-shaped profiles are thus to be found in valleys whose directions coincided with this, e.g. the Mawddach under Precipice Walk and, farther south, the Tal-y-Llyn—Dysynni valley. The former appears to have been occupied by ice to a height of at least 900 feet, and the spurs coming down from Y Garn both upstream and downstream from Llanelltyd (Nos. 7 and 8, Fig. 30) are steeply truncated up to this height ; so, also, are Foel Ispri (No. 5) and Y Vigra (No. 3).

Valleys transverse to the direction of flow, and this includes all the rejuvenated tributary valleys to the estuary, were little affected, and preserved their form almost unaltered, apart from some filling with drift which has largely been cleared since.

The details of the glaciation, especially the relation in time and space of the Cader ice and the regional glaciation, await full study. But some interesting low level overflow channels of late glacial origin have been observed and are described below. In being marginal to the Mawddach glacier they differ from the series described by O. T. Jones and W. J. Pugh in the Dovey Valley [**10**, p. 289]. There the effects are attributed to damming by Irish Sea ice after the withdrawal of the Central Wales ice. The overflows thus occur in aligned sequence from lakes impounded in one tributary valley, escaping over the col into the next to the south, the final exit to the coast being probably along the Clarach valley north of Aberystwyth.

LATE GLACIAL OVERFLOW CHANNELS

During the shrinkage and melting of the Mawddach glacier an interesting series of marginal channels was cut by melt waters descending the tributary valleys and the slopes of the main valley above the glacier. Since the main valley follows the direction of strike the marginal channels necessarily do the same, and they have generally enlarged and altered pre-existing strike hollows along the outcrops of less resistant strata. They possess, however, certain

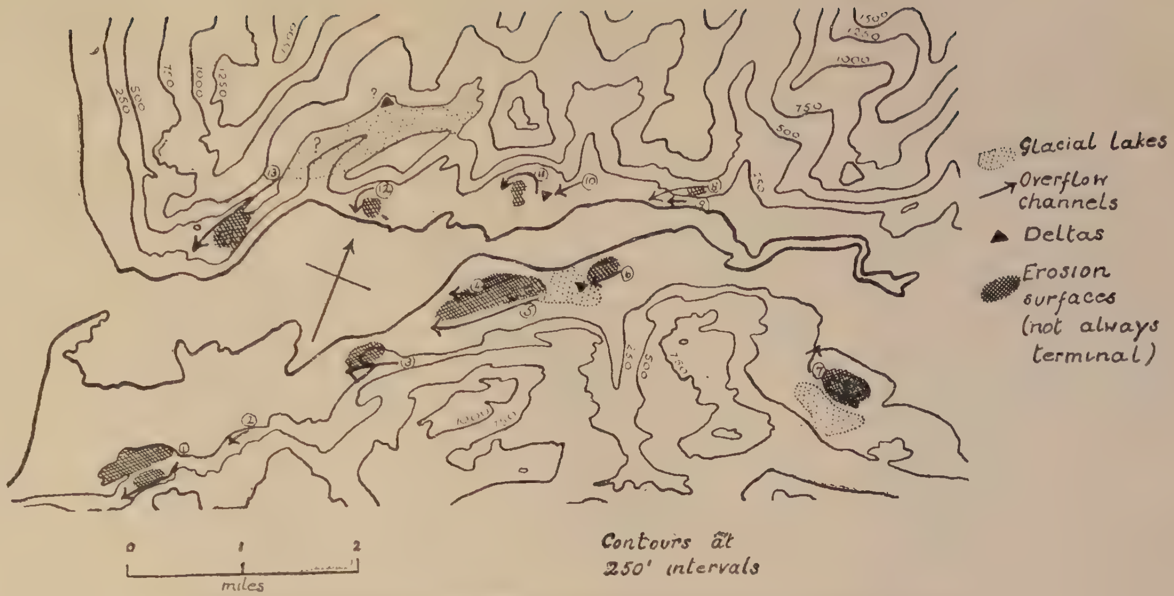

FIG. 32.—OVERFLOW CHANNELS AND THEIR RELATION TO EROSION SURFACES.

features which distinguish them from the normal types of strike hollows, and they all conform to the following pattern :—

(1) They have a continuous fall, without any reversed slopes, from an intake at the up-glacier end (the east or north-east) to their point of discharge. No similar valley drains from this watershed in the opposite (up-glacier) direction.

(2) Their floors are either dry, or they are occupied by insignificant streams quite incapable of producing valleys of the size actually existent, which is sometimes very considerable.

(3) Their floors are rounded, but occasionally flat (aggraded) and are usually occupied by coarse gravel.

(4) Some of them, which discharged into lakes, terminate in a delta.

Many, in fact most, of the channels are closely related to the erosion facets previously described. They follow the line at the foot of the back slope and thus have the effect of severing the shelf from its attachment to the hillside and isolating, as a knoll or ridge, what had previously been a bevelled spur. It is noteworthy, too, that the larger ones all lead westwards, intaking from high up the sides of tributary valleys, whose melt-water discharge they have carried round the corner by severing the spur. Many of them come to an abrupt end and hang, sometimes as much as 200 feet, above a valley of a very different type. This probably marks the height of the contemporary ice surface at the point of escape.

The positions of the channels are shown on Fig. 32, and they will be described in turn, working up the estuary on the south bank and returning to the mouth on the north side, as numbered on the map.

(1) **Tyddyn Sieffre Channel** (Fig. 33)

This severs a rounded ridge, representing the 450-foot stage, from the steep wooded slopes known as Gest Ddu, which rise abruptly to 800 feet. The intake is at 320 feet at a point about 100 yards east of the bench-mark 296.1, but soon turns left through 45°, keeping close to the east side of the col. The col itself is occupied by drift and a conspicuous lobe of moraine is intruded some way southward into it. A good section of this moraine is seen in the overburden of the upper Tyddyn Sieffre quarry (disused).

It is probable that the water of the two streams from Hafod-y-gareg, impounded by ice in the embayment of Tyddyn Sieffre, worked round the hillside and contributed to the overflow. In its middle section the channel is much obscured by quarry tip from the upper slate quarries, but below this it is a magnificent feature, 200 feet deep and 100 yards wide, with a gently rounded floor carpeted with good grass, and it carries no stream at all.

The intake is in Tremadoc slates, formerly worked at both the upper and lower quarries, but about half-way it cuts obliquely across a considerable fault and ends in Dolgelley beds. The channel ends abruptly at the farm at Pant Einion and its lower end hangs about 100 feet above the rejuvenated valley of the Pant Einion, which has descended some spectacular falls about 200 yards upstream.

(2) Capel Horeb Channel

This is a small affair, severing a wooded hill from the slopes of Coed Pen-y-wern. Its intake at Braich-y-goes-wen is at about 150 feet, and it continues down to about 70 feet at Afon Morfa, where it hangs above the Cwm Pen-llydan stream.

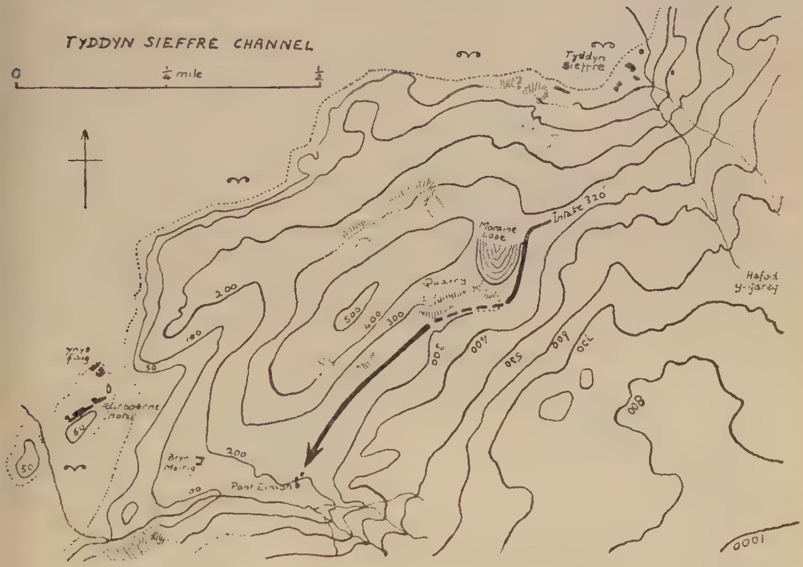

FIG. 33.—TYDDYN SIEFFRE CHANNEL.

(3) Tyn-y-coed Channel

Named from the huge abandoned quarry, Chwarel Tyn-y-coed, on its east flank, which partly obscures the channel with its tip. It severs a knoll, 300 feet high, with a rounded summit, which represents the Ynys stage, from the steep riser to an upper shelf at 500 feet representing the Rhyd Wen stage.

The main road climbs over the intake at Ty-Newydd (Benchmark 216.4) and the channel is immediately well-marked and graded. It falls steadily to a point above Tyddyn Bach at a rate of about 1 in 30. For the last quarter of a mile its right bank is partly destroyed by encroachment of a small but vigorous stream from Erw Goed. The lower end hangs from above Tyddyn Bach.

(4) Coed-y-Garth

This is a small but neat channel taking the overflow from the impounded waters of a small valley on the western wooded slopes of Coed-y-Garth. It intakes just below 100 feet and is traceable to 50 feet above O.D., where it hangs. The floor, though boggy in places, carries no stream.

(5) Llyn Jericho Channel

This severs the wide expanse of Ynys stage at 200 feet on Coed-y-Garth from the steep slopes of Ffridd-y-Garth, on which is preserved a relic of the Rhŷd Wen stage. It is the overflow from the Abergwynant lake, described below. Llyn Jericho is the surviving portion of a more extensive lake now reclaimed by peat and marsh plants. The intake, 300 yards south-west of the lake, is at 80 feet and the channel is long, straight and narrow, increasing steadily in depth. The first quarter-mile is dry, after which small streams enter the channel from the sides and gradually contribute to a sizeable stream which reaches the sea, after a right-angled bend, at Garth Isaf. For the last half-mile of its course this stream is entrenching itself, to a depth of about 50 feet, in the floor of the channel, which can be traced as a grassy shelf, underlain by gravel, on the S.E. side of the stream. The fall is thus only 30 feet in 4,500 feet (1 in 150 feet) ; it is the longest and flattest channel described.

(6) Abergwynant Channel

This channel follows the strike of Ffestiniog beds and severs the wide expanse of the Ynys stage at 200-300 feet in the Abergwynant woods. It is of special interest because it discharged into a considerable lake impounded by ice lying across the present mouth of the Gwynant stream. The level of the lake was determined by the level of the Llyn Jericho overflow described above ; so the ice-dam at the present river mouth stood higher than this. The intake is at Tyn-y-Graig at about 140 feet and the well-graded channel falls to about 80 feet at the Fish Pond in a distance of 1,800 feet (1 in 30). Below the pond is an excellent delta, the height of whose surface corresponds closely with that of the Llyn Jericho outlet. The lake flat, nearly half a mile across, is floored with coarse alluvial gravel, but its western embayment is filled to a height of more than 50 feet with moundy, coarse gravel. The moundiness is partly due to subsequent dissection and partly to the opening of gravel pits.

(7) Maes Angharad Channel (Fig. 29)

The great spread of peat in the Rifle Range channel (see Fig. 29) and its extension as a long arm up the valley north-eastwards to a col near Llwyn Isarth suggests a glacial lake. Moreover, there is good reason to expect that Wnion valley ice, issuing into the Dolgelley depression, would spread up the slopes and valleys south of the town, impounding the drainage of the Cader Road stream. The rejuvenated lower reaches of the stream, as has been shown on page 191 were already in pre-glacial times encroaching on the middle reach, graded to the 200-feet level, which drains the lower end of the Rifle Range swamp.

At maximum glaciation the whole of the 450-foot erosion surface here must have been covered. There is a large moraine from Tyn-y-Llwyn to Maes Angharad, which may represent a temporary front, though it may have been made by ice from Cader and Mynydd-y-Gader. But at some stage in the retreat the 450-foot platform was exposed, though the outlet along the Cader Road remained obstructed. Drainage from the slopes of Dolgledr, plus melt water, accumulated in the Rifle Range depression. The overflow occurred about 300 yards S.S.E. of Maes Angharad at about 415 feet; a barn is built in the intake channel. From here a deep valley with a very steep wooded right bank descends to the ford south of Glyn Malden. It is practically dry in the upper part, but soon accumulates local drainage and is a sizeable stream by the ford.

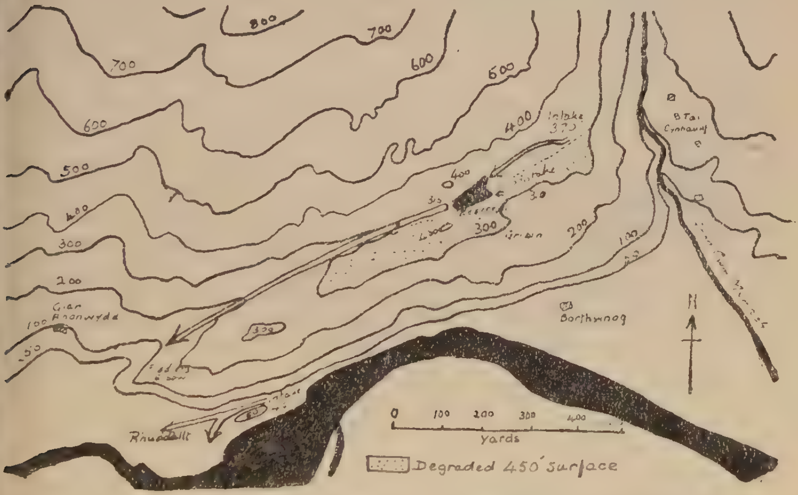

FIG. 34.—FIDDLER'S ELBOW AND RHUDDALLT CHANNELS.

(8) **Fiddler's Elbow Channel** (Fig. 34) flows behind a steep ridge at 400 feet, known as the Gribin, perhaps a degraded remnant of the Rhŷd Wen stage. It probably carried some of the drainage

of the Cwm Mynach valley, whose lower end was then obstructed by ice. The higher intake at 370 feet leads off from this valley, but there is also a lower intake round the corner, now dammed to form a small reservoir for Borthwnog house at 310 feet. The dam raises the water level of the reservoir to about 315 feet, when it spills over into the natural overflow channel. This narrow dammed gap may have been produced by a small post-glacial stream crossing the overflow channel ; if pre-glacial it must have been obstructed while the overflow was operating. Except when the reservoir is full the overflow channel is dry and quite characteristic down to about 100 feet, where it becomes a ravine to the Fiddler's Elbow.

(9) **Rhuddallt Channel** (Fig. 34)

This is a small affair, only about 150 yards long, intaking at about 40 feet and falling to the estuary at Rhuddallt.

(10) **Bontddu Channel** (Fig. 35)

This severs the tip of the spur that runs S.E. from Y Vigra and probably carried the waters from the Bontddu valley from a small ice-blocked " Marjelen See " at Bontddu village. The intake is just below the village school at a height a little less than 50 feet and is followed by the main road. It is dry, apart from marsh produced by a causeway road, and falls steadily towards the great horse-shoe shaped depression round Farchynys. Here it spreads out into a dry delta, whose lower end is slightly truncated by the Farchynys channel which exposes about two feet of peaty soil. This suggests that the Farchynys depression is later.

(11) **The Farchynys " Horseshoe "** (Fig. 35)

This differs from the overflow channels hitherto described in many important respects.

1. Its shape, suggestive of an abandoned meander or an " in and out " depression.
2. It does not fall continuously from " intake " to " outlet," but is drained in both directions from a central divide. I have not been able to determine the height of this divide accurately, for the bench-mark (23.9) in the wall near by has disappeared, but it is about eight feet below this wall and is thus probably about 15 feet above O.D.
3. It is floored continuously with peat, and is boggy, with a vegetation of *Juncus* in the eastern half and *Sphagnum* and bog myrtle in the western. The driest point, at which there is grass turf, is where a wall and road cross the depression about 200 yards east of the divide.

At its S.W. end near Farchynys Farm it grades with the estuary alluvium and probably passes beneath it. Thus when in full operation it probably discharged into water below the present sea-level. There may be a buried channel from here to the flat aggraded hollow followed by the road beyond the drive to Farchynys between a low wooded ridge and the rocky slopes of Allt Boeth. If so it would have passed well below present sea level by this point.

Whether the Farchynys hollow represents an abandoned course of the Mawddach, or a glacial diversion, or a combination of the latter following the former, it must have carried a considerable volume of water continuously in one direction, downstream. The presence of a divide must, therefore, be of later development and is probably due to weathering and erosion of the peat infilling.

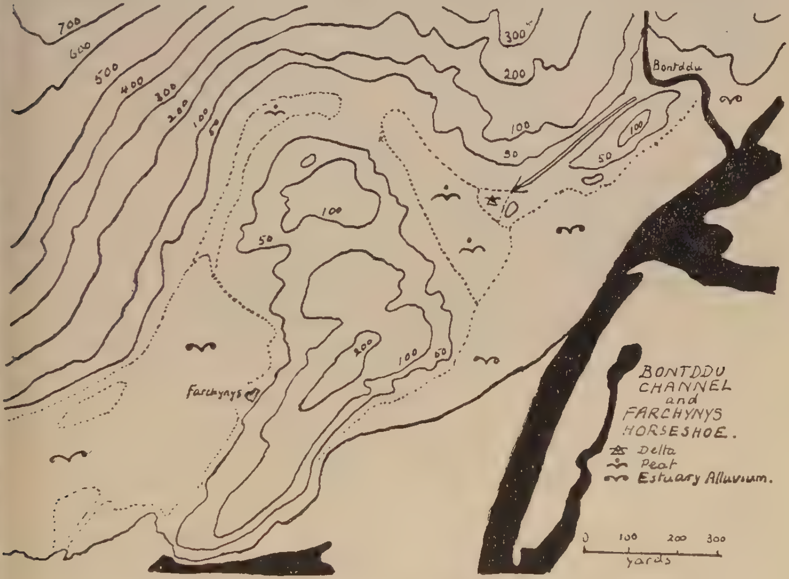

FIG. 35.—BONTDDU CHANNEL AND FARCHYNYS HORSESHOE.

It is worth noting that the Mawddach channel narrows at this point to about 300 yards between steep rocky headlands, each preserving on its summit relics of the Ynys stage. It is not possible to say which was the actual channel before the dissection of this stage.

(12) **Ynys Dafydd Channel**

A short channel severing the wooded hill of Ynys Dafydd (a degraded relic of the Ynys stage) from the rocky hill of Garth (500 feet). Intaking at about 70 feet it is wide and grassy past Glandwr Uchaf, soon after which it escapes southwards. At an earlier stage this southward outlet was probably obstructed by ice and the melt waters discharged westwards past Glandwr.

(13) Panorama Walk Channel

This lies behind the rough rocky ridge of Llwyn On and its continuation southwards, from which the famous Panorama view up the estuary is obtained. This ridge of Maentwrog beds is very rough and deeply scored with glacial grooves and striae ; it probably represents a relic of the 450-foot stage. The overflow channel practically follows the junction between the steeply dipping Clogau beds, with intrusions of hornblende porphyrite, and the Gamlan beds and Barmouth Grits that form the high rough ground of Garn. The intake is at about 540 feet and the channel is straight, deep, wide-floored and dry. It is clearly marked as far as the head of Orielton woods at 200 feet, having descended 340 feet in 4,300 feet (1 in 14). At this point the channel changes its form and a small stream, which has entered from the west, plunges down a steep ravine through Orielton woods to enter the estuary by a culvert under the road at the bend of the road at Aberamffra Harbour.

From its large dimensions this channel has clearly carried a considerable volume of water and probably took the drainage of the Glandwr tributary, which was led round the corner and across the spur by an ice block across its lower end at Glandwr Mill.

In view of the possibility of a large lake standing at 540 feet (the height of the intake) in the Glandwr valley it is interesting to note the existence of a large flat swampy area in the mature upper part of the valley above the rejuvenation head, which is found just above the 400-foot contour. This peat-floored flat extends for nearly a mile upstream and is about a quarter of a mile wide. Furthermore, at Tyddyn Pandy, where a tributary comes in from the north-west, is a sloping delta-like shelf with a steep front-face towards the " lake." This striking and unusual feature is at exactly the right height (530 feet). Crags of solid rock project through it in places, but the smooth, grassy surface flows unbroken round them. Nowhere is there an exposure to show the construction of this feature except by the bridge across the river at about 480 feet, where about 30 feet of boulder clay can be seen : this clearly underlies any delta deposits.

Similar features might be expected in the main river at the same height, but the ground here is very rough with many ridges of outcropping rock, part-buried by aggradation which produces smooth grassy spreads between the projecting crags.

THE ESTUARY

The conversion of the Mawddach valley into a tidal estuary is the last notable event in its geological history and may, by analogy with the other estuaries of Wales and Western England, be attributed to the Neolithic submergence. The amount of submergence is difficult to estimate and impossible to determine with accuracy, but Professor O. T. Jones [9], reviewing the geological history of this coast and its estuaries in an introduction to a noteworthy paper on the Dovey marshes, says: "It is known that in several places along the Cambrian Railway the solid rock is more than 80 or 90 feet below the level of the Dovey Flats, while near Dovey Junction the rock floor lies more than 150 feet below sea level." T. Codrington [8] reviews the depth and form of the bottom of our submerged rock valleys and shows that depths of 50 to 80 feet below low water mark may be expected. In the Mawddach the bottom has not been found, but H. Conybeare [7], giving an interesting account of the engineering problems involved in constructing the Barmouth Viaduct and Bridge, shows how the rock bottom was traced by the cylinder foundations to 40 feet below the level of low water (i.e.—45 feet O.D.), where it was shelving rapidly downward beneath a bed of peat of unascertained thickness, too deep to be penetrated for foundations.

About 1900 the foundations of the bridge were reconstructed and caissons penetrated the bed to a depth of 76 feet below O.D.[1] Two cylinders reached bed rock, No. 1, 38 feet from the Barmouth shore at —70 feet O.D., and No. 2, 78 feet from the shore, at —76 feet. The cylinders are 8 feet in diameter and only the inner edge of the outer cylinder reached rock, where it was concreted into place; it is clear that the bottom is still shelving at 76 feet below O.D. The section is as follows :—

H.W.M.O.S.T.		+12 ft.	O.D.
L.W.M.O.S.T.		—5 ft.	,,
Ground level		—22 ft.	,,
Dirty sand and large stones (probably the stoning of shifting sands in the foundation of the original bridge)	13 ft. to	—35 ft.	,,
Clean coarse sand	2 ft. to	—37 ft.	,,
Clayey mud	27 ft. to	—64 ft.	,,
Stiff mud and oyster shells	4 ft. to	—68 ft.	,,
Blue clay	8 ft. to	—76 ft.	,,
"Granite" rock			

There is no mention of the peat bed referred to in the previous account, which is apparently in the "clayey mud."

Another line of approach would be the extrapolation of the rock floor profile of the river from where it is last seen. This point, however, is about three miles above Dolgelley in the Wnion and nearly as far above Llanelltyd in the Mawddach; from these points downstream the river bed is continuously aggraded with valley or estuary alluvium. Furthermore both rivers are rejuvenated above the aggradation, and it would be misleading to extrapolate an ungraded reach. Finally, the union of many tributaries near Dolgelley and Llanelltyd must have resulted in a thalweg for the combined stream that bears no relation to those of its components. No attempt, therefore, has been made to arrive at the depth of submergence at Barmouth on these grounds. It must be assumed, from the evidence of the railway bridge, that the depth of rock bottom exceeds 76 and is perhaps more than 100 feet below O.D. O. T. Jones [**10**, p. 300] says : " The depth of the rock floor in the Dyfi estuary at Glandyfi is more than 130 feet below O.D., and that of the Barmouth estuary is more than 120 feet." It seems that this is from verbal evidence, and I have been unable to find any confirmation.

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[1] Information and plan kindly supplied by the Chief Engineer, G.W.R.

The prevailing S.W. wind, which is also the dominant wind by virtue of its long uninterrupted fetch from the Atlantic through St. George's Channel and across Cardigan Bay, has built a long recurved sand and shingle spit across the estuary from a point of attachment near Friog. In the lee of this spit natural reclamation is proceeding fast, on the drier parts of which the holiday resort of Fairbourne is growing up. The spit concentrates the flow of the tide on the north side of the Estuary and gives deep water at Aberamffra Harbour beneath the rocky promontory on which Barmouth stands. The tidal current here sets very strongly under the north bank (often 9 knots) and causes great scour, which plays havoc with the shifting sands around the foundations of the bridge, which had, therefore, to be stabilised by heavy stoning. The tidal range at Barmouth is 17½ feet at spring tides and 13½ feet at neaps[2] and the effect of the tides is felt for seven miles upstream as far as Llanelltyd bridge, where the flood plain is about 16 feet above O.D. and liable to floods (not from tides, but from land water).

Below Penmaenpool the ebb lays bare acres of golden rippled sand through which the river meanders in anastomosing channels. Above Penmaenpool the alluvium is mostly fine mud. Here, and on either side of the estuary sands, in sheltered places, the mud flats are being colonised by salt marsh, which provides interesting examples of the different stages in the process. The stages appear to be similar to those in the Dovey marshes so fully described by Jones, Johns and Yapp [**9**].

I wish to thank the Research Board of the University of Reading for a grant towards my expenses, and to acknowledge my great indebtedness to Professor Cox for much advice and discussion in the field and for facilities generously given to copy drift boundaries and other geological lines from the 6-inch M.S. maps prepared for the Geological Survey.

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[2] Information supplied by the Harbour Master.

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DISCUSSION

Prof. O. T. Jones was interested in the area described by Prof. Miller, but did not think it was particularly good for the purpose on account of the heavy glacial effects. The speaker hoped that he had set an example to be followed by other investigators of river profiles by levelling the floors of the main valleys and their tributaries, but he was sorry to find that this example had not been followed although it was the only way to obtain data which were objective and did away with too much of the personal equation in their interpretation. The 400ft. base-level was, of course, well developed on the west coast of Wales and the speaker was glad to find that Prof. Miller recognised that the remnants of it occurred at successively higher levels up valleys. This disposed of any possibility of explaining them as due to marine erosion. The evidence for the higher level and in particular for the 200ft. level was not so satisfactory and there did not seem to be any evidence for it farther south in Cardigan Bay where the glacial effects were less marked. It was always difficult to be sure that apparent shelf remnants on valley sides were not glacial deposits, the surface of which bore little relation to the level of the solid rocks below them. New techniques were required to deal satisfactorily with such areas. It has been claimed that the 200ft. level is well represented in South Wales, but it is not clear that this surface is not in fact the continuation of the 400ft. platform farther north warped down subsequently, possibly even in post-glacial times.

Dr. R. O. Jones congratulated the author on his clear presentation of the paper and said that he looked forward with great interest to its publication. He agreed with previous speakers that the evidence in the district for the 200ft. base-level did not appear to be as convincing as it was in South Wales.

He enquired whether the author had found any indications of a base-level at about 600ft. for which there was some evidence farther to the south, and also whether he had found any higher glacial overflows along pre-existing dry valleys which had been abandoned through earlier river capture.

AN OUTLINE OF THE GEOLOGY OF THE KETTERING DISTRICT

By S. E. HOLLINGWORTH, M.A., D.Sc., and J. H. TAYLOR, M.A., Ph.D.

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[Written for the Whitsun Field Meeting, 1946]

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I. INTRODUCTION

THE Geologists' Association first visited Northamptonshire (Northampton and Stamford districts) in 1874 under the leadership of Samuel Sharp whose two papers on the Oolites of Northamptonshire had recently appeared (1870, 1873) and a sketch of the geology of the county was published in the Association's *Proceedings* for 1873.

Since that time several day and week-end meetings were led by that pre-eminent Northamptonshire geologist Beeby Thompson between the years 1890 and 1921 including one to Kettering. By far the greater part of our knowledge of the geology of the county is due to that gifted amateur and general accounts have been written by him for the Association's Jubilee Volume (1910) and for the Victoria County History.

More recently Mr. L. Richardson has led a series of excursions demonstrating the relations of the Jurassic rocks of the Cotswolds with those of Northamptonshire (Towcester 1921, Kettering 1937 and Stamford 1938).

For standard accounts of the geology of the county in relation to other areas, the Geological Survey Memoirs by H. B. Woodward on the Lias and Lower Oolites (1893, 1894) and Dr. Arkell's comprehensive modern account (1933) should be consulted.

During 1939-43 a special investigation of practically the whole of the Northampton Ironstone Field extending from Towcester in the south-west to beyond Grantham in the north was carried out by the Geological Survey under the supervision of Mr. T. H. Whitehead. This involved a six-inch-to-a-mile geological survey of the actual and potential ironstone-bearing areas with special attention to factors affecting the exploitation of the ironstone. From the mass of new and unpublished information it seems desirable to bring together the salient features that have direct application to the geology of the district to be visited by the Association at its Kettering Meeting.

II. OUTLINE OF THE GEOLOGICAL HISTORY OF THE DISTRICT

The district dealt with in this sketch may be defined as lying within the polygonal area bounded by lines joining Northampton, Rushden, Thrapston, Oundle and Harringworth, with Kettering occupying a fairly central situation (Pl. 15).

Liassic and Lower Oolitic strata occur at the surface in this mid-Northamptonshire region. These Jurassic beds have a very gentle easterly to south-easterly tilt and so give an impression of a region whose geological history is one of extreme simplicity. The few deep borings that have been made through these rocks, however, give meagre clues to an earlier history of considerable complexity. A striking feature of these boreholes is the failure to prove any representatives of Lower Palaeozoic strata. Thus two holes, one at Orton, 4½ miles west of Kettering and one at Great Oxenden, 4 miles west of Desborough, entered igneous rocks assumed to be Pre-Cambrian after passing through Lias and a small thickness of Rhaetic and Triassic beds.

Farther south, at Northampton and at Gayton 5 miles to the south-west of Northampton, thin Triassic beds were underlain by Lower Carboniferous strata. At Gayton the basal beds of the marine Carboniferous only have survived and red grits, sandstones and marls resembling Old Red Sandstone were proved below.

There are thus suggestions of two great unconformities, one possibly representing the whole of Lower Palaeozoic time and the other definitely the greater part of Carboniferous and Permo-Triassic times. The latter break ended with the submergence of an old landmass beneath the uppermost Trias and transgressive Rhaetic-Liassic Sea.

Evidence has been advanced for the existence of gentle intra-Jurassic folding during Liassic times with anticlinal axes along the Nene valley 8 miles west of Northampton and through Market Harborough, some 10 miles west of Corby ; but movement along those lines is considered to have ceased before the deposition of the Oolitic strata. (Cox and Trueman, 1920.)

The partly marine, partly estuarine beds of the middle Jurassic rocks between the Lias and the Oxford Clay are all shallow-water deposits with abundant internal evidence of local erosion, non-sequences and unconformities. The local stratified record of the

Mesozoic ends with the Oxford Clay. No Tertiary rocks are present and the next records are of Pleistocene deposits that are later than the main phase of late-Tertiary valley cutting.

The possible former extent of the Upper Jurassic (Kimmeridgian Portlandian) and Lower Cretaceous beds over the area is problematical ; but the Chalk sea of the Upper Cretaceous is generally considered to have covered this region. The Tertiary epoch was probably associated with a renewed emergence accompanied by some easterly tilting. The present easterly to south-easterly dip probably represents the cumulative effect of slight tilting which went on intermittently up to Pliocene times.

The Present Erosion Cycle. Practically the whole of the area is drained by the River Nene and its tributaries. The principal tributaries are (1) the many headed ‘ western branch ’ of the Nene from Weedon which is joined at Northampton by (2) the northern or Maidwell branch ; (3) the Ise flowing first east from Arthingworth to Geddington and thence south by Kettering to the Nene at Wellingborough, and (4) the Harpers Brook which, rising north of Desborough passes eastward to Stanion and thence south-south-east to the main river at Thrapston.

The extreme north-western portion of the area falls within the drainage basin of the River Welland : and the watershed separating Nene and Welland catchment areas runs along the top of the escarpment of the Inferior Oolite which overlooks the Welland between Wilbarston and Harringworth.

These rivers drain a rolling, well-dissected agricultural region falling from 500 ft. O.D. in the west to around 250 ft. O.D. in the east. Much of the higher ground is covered by boulder clay. From the distribution of the drifts, notably in the presence of pre-glacial gravel and sand at low levels, the tendency for valley heads to be drift-filled, and the existence of certain surviving drift-filled valleys it is clear that a mature river system broadly similar to that of today existed in pre-glacial times.

East-west profiles suggest the possibility that the summit levels of the sub-drift surface may represent an ancient plane of erosion on which, following uplift and tilting, the present river system was initiated. In passing northward from Kettering the undissected plateau-like remnants corresponding to such a surface become more prominent and beyond the area under consideration there are large unbroken plateaux across which the outcrops of successive formations are bevelled off and make no distinctive features.

III. THE IRONSTONE INDUSTRY

Exceptional opportunities for studying the geology are afforded by the extensive ironstone workings in the district. The total length of quarry-face sections must amount to many miles and exposures of all beds from the Upper Lias Clay to the Cornbrash can be seen in them.

The Northampton Sand Ironstone is known to have been worked in Roman times and the slag found at various points in the Ironstone Field is believed to be in part of Roman age. " Ferraria " are recorded in the Domesday Book from Gretton and Corby in Edward the Confessor's reign. Later records show that royal furnaces were in work at Geddington in the reigns of Henry II and Henry III. Rockingham Forest, like the Weald of Kent and Sussex, was, in medieval times a great iron producing district. Its decline was due to the same causes, i.e., the prevention of further destruction of timber for charcoal-burning and the discovery that coal could be used for smelting, with consequent transference of the industry to the Coalfields. (Judd, 1875, pp. 110-112.)

The construction of railways in the middle of the 19th century led to renewed working of the Jurassic ironstone. Not only was attention drawn to the outcrops of ore on the sides of the valleys followed by the railways, but an easy means of transport between Coalfield and Ironstone Field was provided.

The earliest recorded workings in Northamptonshire were at Blisworth and Gayton, south of the area at present under consideration. In 1857, however, ironstone was exposed in a cutting near Desborough during the construction of the railway from Hitchin Junction to Market Harborough and working was commenced at Desborough in the same year. Within the next 20 years pits were opened up in rapid succession in the neighbourhood of Brixworth, Wellingborough, Irchester, Finedon, Kettering, Glendon, Cranford and Islip. The construction of the Kettering-Manton line, opened in 1879, drew attention to the presence of ironstone in the neighbourhood of Corby and working was commenced shortly afterwards. This activity in the working of ironstone was followed by the rise of local smelting. During the latter half of the 19th century blast furnaces were constructed at 10 different places in Northamptonshire, although the bulk of the ore continued to be smelted outside the district.

All the older workings were in the form of open quarries from which both overburden and ironstone were removed by hand. In the closing years of the last century mechanical excavators were introduced into the Ironstone Field giving increased output and economy of labour. Apart from small mines operating for a few years at Cogenhoe and Woodford in the 1870s underground mining did not develop until about the beginning of the present century. With the growth of the iron industry the working of Lincolnshire Limestone and Great Oolite Limestone for use as a flux in the furnaces and of Lower Estuarine silts for refractory purposes increased in importance. During the war of 1914-18 the unprecedented demand for iron and steel led to increased activity ; but many of the pits failed to survive the ensuing depression.

Despite the long history of the Northampton Ironstone Field, prior to 1930 no steel works had been based upon it. Its products were in the main forge and foundry pig-iron though a certain amount of the ore was sent to other districts for the production of basic iron for steel. In the early 1930s, however, a plant to produce basic Bessemer steel was erected at Corby.

The war of 1939-45 once again stimulated activity. New pits were opened and old ones reopened. During this period, in the area under consideration, three mines and more than forty opencast quarries have been working. The most modern methods of extraction involving the use of electrically driven quarry-shovels and draglines together with tractor-scrapers have allowed a greatly increased thickness of overburden to be handled. An excellent account of working methods has recently been published by Dr. W. D. Evans (1945).

In 1943 production from Northamptonshire amounted to more than 6 million tons. Including that from adjacent areas in the counties of Lincolnshire, Leicestershire and Rutland 9½ million tons—more than half the total British output of iron ore—came from the Northampton Sand seam.

IV. JURASSIC ROCKS

The solid geological formations represented in the southern part of the Northampton Ironstone Field are as follows :

				Approximate thickness Feet
Jurassic		Oxford Clay		100+
		Kellaways Beds		up to 25
		Cornbrash		0–8
	Great Oolite Series	Great Oolite Clay		10–20
		Great Oolite Limestone		15–25
		Upper Estuarine Series		15–45
	Inferior Oolite Series	Lincolnshire Limestone	Upper	0–40
			Lower	0–40
		Lower Estuarine Series		0–25
		Northampton Sand with Ironstone		0–40
		Upper Lias Clay		up to 185

Upper Lias. The blue and blue grey clays of the Upper Lias are not extensively exposed in our area. Brickpits have in the past afforded sections, but many of these are now largely obscured. The sections at Wellingborough, Kettering and Corby are still in a reasonably good state of preservation.

In the ironstone workings the Lias is only visible in drainage trenches generally of a temporary nature. These exposures locally afford evidence that the Northampton Sand rests directly on the *bifrons* zone. For example, the top 15 feet of the Lias clay at Cowthick Pit east of Stanion contained *Hildoceras bifrons* (Bruguière) and *H. hildense* (Young and Bird), together with *Inoceramus dubius* (J. de C. Sowerby) and *Nuculana ovum* (J. de C. Sowerby). The uppermost beds of the Lias in Church Mine near Islip have also yielded *Hildoceras bifrons*.[1]

Northampton Sand. The area north and west of Northampton is the type area for the Northampton Sand. Hereabouts the rich yellow and orange-brown sandstones were much appreciated as a building stone long before the value of certain parts of the formation as a source of iron was rediscovered.

S. Sharp (1870) used the term Northampton Sand to include all the beds from the Upper Lias to the ironstone-nodule bed at the base of the Great Oolite [Series] and separated lower, middle and upper divisions that were usually represented by ironstone, ferruginous and calcareous sandstone, and white sand respectively. His upper division represented part of the Lower Estuarine Series of the Geological Survey (Judd, 1875)—a term which Sharp accepted. Judd used the expression "Northampton Sand with Lower Estuarine Series," and this close linking of these two formations has tended to persist. Thus Beeby Thompson (1921-8) regarded the Lower Estuarine "White Sand" as part of the Northampton Sand and Arkell (1933) generally follows this usage. H. B. Woodward (1894) utilised the term Northampton Beds to include two distinct formations (1) the Northampton Sand and (2) the Lower Estuarine Series. Wedd (1920) followed Woodward in regarding (1) and (2) as distinct formations, but abandoned the term Northampton Beds. The resurvey has demonstrated that the Lower Estuarine Series is unconformable on the Northampton Sand, with strongly contrasting lithology and conditions of deposition. Wedd's usage best fits these facts and has been adopted.

The Northampton Sand is a sandy, ferruginous and calcareous formation of great variability. It seldom exceeds 30 feet in thickness in our area; though west of Northampton more than twice that thickness of ferruginous sandstone has been recorded.

The formation may be regarded as having been present over practically the whole area prior to the cutting of the present valley system. To the south-east, however, it is thin; and it dies out rapidly to the east and south beyond the Nene, so that Estuarine beds rest directly on the Upper Lias. North of the Nene there are a few localities where Northampton Sand is missing beneath the higher beds of the Inferior Oolite Series, as for example the wedge-shaped area tapering northwards from Great Doddington. The formation is also abnormally thin or absent over a narrow belt of country west of the Ise extending as far as Pytchley. This belt appears then as an incipient anticline or region of non-deposition or pene-contemporaneous erosion separating areas of contrasting lithology to the east and west where the formation is much thicker. The effects of this anticlinal line are most marked in the south, where it merges into the Doddington wedge, and they die out to the north as the latitude of Kettering is approached.

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[1] Fossil names have been provided by Mr. R. V. Melville.

For descriptive purposes the two type areas—a western and an eastern one—are required.

The successions in these two areas have, in spite of major differences, sufficient points of similarity to justify a common terminology. This is given in the table below and has been used in the construction of the diagrammatic section (Pl. 16, A) showing the mutual relations of the two types in the southern part of the district. The inferred equivalence of the individual groups is based wholly on lithological characters.

Western Area.	Thickness (Feet)	Eastern Area.	Thickness (Feet)
		(e) *Upper Chamosite-Kaolinite*[1] *Group* dominantly chamositic and kaolinitic rocks more or less sandy in which primary siderite is characteristically absent...	up to 8
(d) *Upper Siderite Mudstone-Limestone Group.* Sandy oolitic limestones and calcareous sandstones, both more or less sideritic with bands of siderite mudstone (Sharp's "Variable Beds")	0–25	(d) *Upper Siderite Mudstone-Limestone Group.* Well defined posts of more or less oolitic siderite mudstones constituting a workable ore; but in places passing into sideritic sandstones	up to 8
		(c) *Lower Chamosite-Kaolinite Group.* Generally similar to (e) above	up to 6
(b) *Main Oolitic Ironstone Group.*		(b) *Main Oolitic Ironstone Group.*	
(ii) Coarse shelly detrital post with much resorted ironstone	1–2	(ii) Shelly rock made up of chamosite ooliths in a predominantly siderite matrix	2–3
(i) Oolitic ironstone, mainly chamosite ooliths in a matrix of siderite, with subordinate calcite and chamosite	10	(i) Oolitic ironstone, mainly chamosite ooliths in a matrix of siderite with subordinate calcite and chamosite. Occasional siderite mudstone bands 1-3 in. thick ...	up to 10

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[1] For a summary of the mineral composition of the Northampton Sand see pp. 13-15.

WESTERN AREA.	Thickness (Feet)	EASTERN AREA.	Thickness (Feet)
(a) *Lower Siderite Mudstone-Limestone Group.* Calcareous and sideritic sandstones and siltstones with a phosphatic nodule bed near the base	up to 12	(a) *Lower Siderite Mudstone-Limestone Group.* Sideritic siltstones, sandstones, mudstones and limestones. Phosphatic nodule bed at base...	up to 8

Western Type.—The beds of the lowest group (a) are seldom exposed in stone quarries or ironstone workings, but appear as part of the overburden of clay pits in Upper Lias, as for example north-west of Pitsford. Here about 4 feet of sandy limestone is separated from the Lias by a 4-inch bed of oxidised siderite mudstone. In mineral line cuttings at Brixworth six feet of ferruginous sandstone and siltstone are exposed.

Exceptionally thick developments of the lower carbonate group are present at Thorpe Malsor, two miles west of Kettering, and at Mears Ashby where 10 feet or more of predominantly calcareous beds have been recorded. Both localities lie not far west of the Doddington-Pytchley axis.

The Main Oolitic Ironstone group (b) is best exposed in the Pitsford Ironstone Co.'s quarry some 5 miles north of Northampton. Most of the stone is a well oxidised oolite, but green cores are present in the lower part of the seam in deeper parts of the pit. The top post (bii) is a massive bed of coarse shelly ironstone made up largely of rewashed ironstone of various types and shell fragments, and may be tentatively linked with the shelly oolite and associated breccia bands at the top of the main oolite bed of the eastern area (Pl. 16, A).

The western part of the area as a whole, e.g. about Pitsford and Brixworth and in the Thorpe Malsor-Desborough-Harringworth belt, is characterised by a high lime content due to a calcareous ground-mass in the main part of the ironstone seam.

The calcareous sandy beds (d) above the workable ironstone are bluish-grey rocks when unweathered, but are usually creamy to brown in shallow quarries presumably owing to the ready oxidisation of the siderite present. Near the surface they have been extensively decalcified.

These beds show considerable variation from quarry to quarry in the area from Harlestone, 4 miles west-north-west of Northampton, eastward to beyond Boughton ; but the term Variable Beds, which carried the implication of lateral equivalence of the calcareous Northampton Sand to the White Sands of the Lower Estuarine Series, does not now seem to be particularly appropriate.

The contemporaneous erosion and channel infilling (p. 217) illustrated on the western side of the section (Pl. 16, A) is based on the evidence seen in Pitsford Quarry.

Eastward from Northampton the calcareous phase gradually becomes less well developed. It is present at Sywell, but at Earls Barton Sand Pit it can be seen finally to die out so that the Lower Estuarine silts rest directly on the workable ironstone.

Northwards from Pitsford sandy calcareous beds, sometimes represented by a white oolitic limestone, persist for some miles, but are extensively decalcified. North-east of Draughton this division is reduced to a few feet of sandy beds underlain by a massive post of sideritic limestone, e.g., at Orton. This latter bed survives as a limestone as far north as Desborough. To the east and north-east a single bed of siderite mudstone caps the main oolitic ironstone for many miles; but this bed is absent in the Thorpe Malsor area, between Orton and Kettering, where the Lower Estuarine Series rests directly on oolitic ironstone near the northern recognisable limit of the Doddington-Pytchley axis.

Eastern Type.—In the area east of the Doddington-Pytchley axis the dominantly calcareous phase of (d), found above the ironstone seam in the western area, is represented by a sideritic facies and the distinctive chamositic and kaolinitic types that characterise groups (c) and (e) make their appearance (see Pl. 16, A).

The Lower Siderite Mudstone-Limestone group (a) is well developed throughout the area. It has been proved in many borings, but is seldom exposed except in pit drainage trenches, e.g., at south end of Cranford South Quarry, and in mineral lines giving access to quarries, e.g., in the Burton Latimer area. Locally it is less siliceous than usual and the beds are of workable quality down to the base of the formation.

Up to 8 feet of oxidised sideritic siltstone are visible on the upper slopes of the old clay pit at the disused cement works at the west end of Irthlingborough, where the phosphatic nodule horizon is also well exposed. In the Irchester area a grey impure limestone up to 4 feet thick and with 30% of lime is recorded from deep bore-holes.

The Main Oolitic Ironstone group (b) can be seen in all working quarries. It is a massive uniform oolite, green when fresh and brown when oxidised, consisting of closely packed ooliths of chamosite in a matrix of siderite with subordinate calcite and a variable amount of chamosite.

The upper part (b) (ii) forms a single massive bed which is usually shelly throughout and persists as a well defined division from Irchester to beyond Cranford. The shells are normally preserved as casts.

Particularly good sections showing the standard succession, together with lateral variations in the development of interbedded bands of dense bluish-grey siderite mudstone and in the development of shelly bands, are available at the Irchester Ironstone Co.'s

Lodge Pit, 1 mile south of Little Irchester. Another feature of this pit is the westward deterioration of the seam by the local erosion of the workable beds (b) and (d) and filling in of channels with unworkable chamositic beds of group (e).

Here, too, there is an exceptionally fine development of a white aluminous mineral filling fissures in the ironstone. This has been usually referred to as allophane, but recent examination of material has shown that several minerals are present, and the assemblage presents interesting features that are still under investigation by Mr. F. A. Bannister.

Wellingborough No. 5 Quarry, south of Finedon, also shows a full development of the eastern type succession with many interesting local features. Both here and at Irchester there is an increase in the amount of chamosite in the matrix in the lowest part of the main oolite group.

In the area extending from Finedon by Great Addington to Ringstead the upper part of the shelly post (b) (ii) contains a good deal of pellety or breccia material made up of redistributed clots of oolite of chamosite-kaolinite facies and there is some interbedding of streaky oolitic mudstone which has usually undergone some secondary sideritisation. These lithological varieties suggest close connection between the upper part of group (b) and the succeeding group (c).

The Lower Chamosite-Kaolinite group (c) is recognisable at many localities in the Finedon-Irthlingborough area where it is overlain by the sideritic group (d). Only in such circumstances can it be distinguished from the Upper chamositic group. The best available exposures are in the working face of the Wellingborough Iron Co.'s No. 5 Quarry, 1½ miles south of Finedon, where these beds can be seen filling channels cut deep into the main oolite bed. Many good sections have also been observed in the Thingdon Mine north of this quarry. Here the rock is a pale green, rather shaly oolitic mudstone with abundant flattened pellets of sandy, silty and oolitic mudstones of the chamosite-kaolinite suite.

The Upper Siderite Mudstone-Limestone group (d) is well developed between Irchester, Finedon and Cranford. It consists of massive well jointed posts of siderite mudstone variably oolitic with occasionally beds of good massive oolite. Usually the beds of this group are workable, but locally with increase of detrital quartz there is a lateral passage to unworkable ferruginous sandstone, e.g., in old quarries a mile east of Cranford. It is 5-6 feet thick in the Cranford South Pit. Near Finedon there is an uneven development owing to the marked channelling or erosion of the beds before the deposition of the overlying group. Rapid variations in thickness are a characteristic feature that is well exhibited along the disused quarry face which extends southward from Finedon for three-quarters of a mile. The pocketing down of the overlying shaly kaolinitic beds may leave as little as a single 1-ft. post of siderite mudstone to serve as a roof in the mining of the stone in the deeper area to the east of this old face. In the Thingdon Mine itself the pockets have been locally cut deep into the underlying main oolitic group. In some such cases the small thickness of good stone left and the inferior quality of the shaly beds as a roof may make mining locally uneconomic.

In the neighbourhood of Corby the group is either absent or represented by less than one foot of siderite mudstone. Further north it is up to three feet thick where exposed at intervals along the escarpment between Rockingham and Gretton.

The Upper Chamosite-Kaolinite group (e). The two principal rock types are (1) green chamosite ooliths in a chamosite mudstone matrix (mudstone with scattered ooliths may locally predominate) and (2) pale grey kaolinite ooliths in a mudstone matrix of similar composition. There appear to be gradations between (1) and (2). The kaolinite facies commonly, but not invariably, has a streaky appearance and a shaly fracture due to a marked flattening of the ooliths to disc-like bodies lying in the plane of the bedding. The group is strongly developed in the Finedon-Irthlingborough area where it occurs in both the chamosite and kaolinite facies.

The chamosite type is present in the Wellingborough No. 5 Quarry face as green oolitic mudstone which appears to pass vertically upwards and laterally into the grey, sandy, kaolinitic and shaly types of oolitic mudstone. In these chamositic-kaolinitic rocks there are irregular hard masses characterised by an abundance of siderite as single and compound spherulites and with colloform habit that is all clearly of secondary origin (p. 213).

The shaly kaolinitic type is very well exposed in the old quarry face south of Finedon where it fills in steep sided channels in the surface of the underlying siderite mudstones.

Shaly kaolinitic rocks are well developed at the Irchester pits and are recognisable at Burton Latimer, Irthlingborough and as far east as Ringstead. In borehole journals they are usually recorded as grey or brown sandy clays.

The precise relations of these beds to the overlying Lower Estuarine silts are obscured by the considerable secondary changes at and near this horizon. Rootlets frequently pass from the silts well down into the kaolinitic group as can be seen along the old face south of Finedon.

A particularly interesting section of the sphaerosiderite-bearing beds is found in the old north-south quarry face $1\frac{3}{4}$ miles S. by E. of Finedon. This is illustrated in Fig. 36, which shows the localised development of joint-wall masses and rounded spheroidally weathering lumps of sphaerosideritic rock in an oolitic chamosite mudstone of group "e." These masses are intimately related to the distribution of small pockets of Lower Estuarine silt in the latter. The section is across the crest of an old Jurassic fold and on this crest the basal *Ostrea*-bearing beds of the Upper Estuarine cut out the Lower Estuarine silts and rest directly on group (e) of the Northampton Sand. The Lower Estuarine beds which appear on the flanks of the fold are preserved on the crest as small pockets only of silts. By this fortunate circumstance, evidence bearing on the age of the secondary sideritisation is afforded, for the section suggests that the formation of the sphaerosiderite is associated with subsoil reactions during the accumulation of the Estuarine beds and so preceded the changes at the end of Lower Estuarine times.

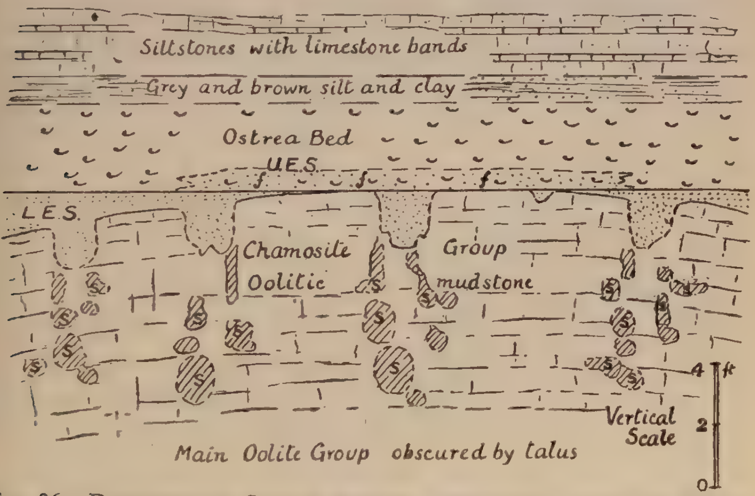

Siltstones with limestone bands
Grey and brown silt and clay
Ostrea Bed
U.E.S.
f
L.E.S.
Chamosite Oolitic Group mudstone
S
Main Oolite Group obscured by talus
Vertical Scale
4 ft
2
0

FIG. 36.—DIAGRAMMATIC SECTION SHOWING DEVELOPMENT OF SPHAEROSIDERITE IN CHAMOSITIC BEDS.

Old Quarry face, ½ mile W.S.W. of West Field Lodge, W. of Irthlingborough. (LES = Lower Estuarine Series ; U.E.S. = Upper Estuarine Series ; S = Spherosiderite masses ; f = ferruginous facies of ostrea bed, restricted to crest of anticline.)

Sphaerosideritic material within the group (e) has been found at Burton Latimer, Cranford, Woodford, Ringstead, Irthlingborough, Irchester and Oundle.

The Northampton Sand has yielded an extensive fauna. This is confined to the Lower and Upper Siderite Mudstone-Limestone groups and to the Main Oolitic Ironstone group. Both of the Chamosite-Kaolinite groups are completely unfossiliferous : it is possible that the absence of fossils may be related to a limedeficient environment, for the rocks are characteristically devoid of carbonate minerals.

Ammonites are rare, but those that have been found are indicative of the *opalinum* zone. *Leioceras costosum* (Quenstedt) has been obtained from the Main Oolitic Ironstone group at Church Mine west of Islip. At Duston, two miles west of Northampton *Leioceras opalinum* (Reinecke) and *Bredyia newtoni* S. S. Buckman occur. The presence of forms which may represent a higher zone has been recorded from the beds above the ironstone proper (" Variable Beds ").

Brachiopods include *Loboidothyris* cf. *perovalis* (J. de C. Sowerby), *Homoeorhynchia* cf. *cynocephala* (Richard) and *Rhynchonelloidea subangulata* (Davidson). Terebratulids of *perovalis* type are common in the Lower Siderite Mudstone-Limestone group and the Main Oolitic Ironstone group at many places, e.g., Desborough, Twywell and the Corby district. *Homoeorhynchia* is particularly abundant in a massive siderite mudstone band immediately overlying the Main Oolitic Ironstone group at Desborough.

Lamellibranchs are locally plentiful in all the three fossiliferous groups of the Northampton Sand. Characteristic species include *Astarte elegans* J. Sowerby, *Lima* (*Plagiostoma*) *overstonensis* Cox, *L.* (*P.*) *castertonensis* Cox, *L.* (*P.*) *northamptonensis* Cox, *Proenoella ferruginea* Cox MS., *Trigonia v-costata* Lycett, *Velata abjecta* (Phillips) and *V. grada* (Bean).

Petrology of the Northampton Sand Ironstone. The principal iron-bearing minerals present in the Northampton Ironstone are the iron alumino-silicate chamosite, the impure iron carbonate siderite (which contains up to 20% of the carbonates of calcium, magnesium and manganese) and the hydrated iron oxide limonite. Other minerals more or less commonly present are calcite, quartz, kaolinite and collophanite.

The rock types in the Northampton Sand are unquestionably chemically precipitated sediments. The theory that such deposits have a replacement origin and that the iron was introduced subsequently to the deposition of the bed (for references see Hallimond 1925) is now completely abandoned. The evidence in favour of the primary nature of the British bedded ores in general, admirably set out by Dr. A. F. Hallimond, has been fully confirmed by detailed study of the Northampton Ironstone.

Although the primary nature of the chamosite and much of the siderite is beyond doubt it is clear that secondary processes have played a part in the formation of the ores. Siderite has locally replaced chamosite and calcite, while limonite has been formed as a result of oxidation of siderite or chamosite. These changes appear to have been in part pene-contemporaneous and to have affected the deposits while still in process of transportation and accumulation. In all probability rapidly changing physico-chemical conditions were obtaining on the sea floor at the time of deposition of the Northampton Sand and this combined with strong current action has given rise to the mixed assemblage of ooliths that is so typical of many beds in the ironstone. Periodic incursions of sandy detritus are evidenced by local abundance of quartz grains throughout the formation.

The rocks of the Main Oolitic Ironstone group consist of a varied suite of ooliths set in a groundmass comprising one or both of the carbonates siderite and calcite, with in some cases the addition of chamosite. The ooliths are made up of chamosite and less commonly of limonite, siderite or kaolinite or of a mixture of these minerals. In some types the material of the ooliths has been completely removed, leaving a cavernous rock. With variations in the character both of ooliths and groundmass it is evident that a wide range of rock-types can result. For purposes of classification the major divisions can be based upon the nature of the matrix and minor sub-divisions upon the constituents of the ooliths. In the nomenclature suggested by the authors, adjectival prefixes are used for the minerals of the groundmass, substantival prefixes for those of the ooliths. Thus a rock containing chamosite ooliths in a siderite groundmass would be described as a sideritic chamosite oolite ; one with limonite ooliths in a groundmass of siderite and chamosite would be termed a sideritic chamositic limonite oolite.

The rocks of the Lower and Upper Siderite Mudstone-Limestone groups are characterised by the dominance of the carbonate minerals siderite and calcite and relative scarcity of chamosite. The most widespread rock type is siderite mudstone consisting of finely granular siderite with occasional scattered ooliths of chamosite. By increase in the percentage of these ooliths the rock grades into a sideritic chamosite oolite. Kaolinite ooliths may also occur. The presence locally of abundant quartz grains gives rise to sideritic sandstones and siltstones. Sideritic limestones consist of abundant organic debris and, in some cases, calcite ooliths set in a calcareous groundmass : through the rock there is scattered abundant granular siderite, that is in part clearly secondary in origin. The channel infillings in the western facies (Plate 16, A) contain abundant sand grains coated with calcite and having the aspect of ooliths. The cement is sideritic with many calcitic patches. On weathering the latter remain white in a ground mass of ochreous tint.

The Lower and Upper Chamosite-Kaolinite groups contain a series of oolitic rocks normally free from carbonate minerals. These types are characterised by a low specific gravity. Chamositic oolites consist of ooliths of chamosite in a groundmass of the same material. Where the proportion of groundmass to ooliths is high the rock might be termed an oolitic chamosite mudstone. Corresponding types in which ooliths and groundmass are composed of kaolinite are kaolinitic oolites and oolitic kaolinite mudstones. The kaolinitic rocks have in general a characteristic streaky appearance resulting from the fact that the ooliths are disc-shaped with their flattened surfaces parallel to the bedding planes. Presumably such ooliths were deposited in a soft condition and have been compressed and flattened before lateral extension was restricted by packing. It seems not unlikely that the kaolinitic rocks may have resulted from the leaching of material derived from chamositic oolites. It is uncertain to what extent this leaching involves erosion and redeposition or merely transportation of ooliths from an environment favourable to the existence of chamosite to one in which kaolinite was stable.

Locally, secondary siderite has been developed in the rocks of the Chamosite-Kaolinite groups. Commonly this is spherulitic, but frequently it has a well developed colloform banding. The spherulitic siderite occurs in conspicuous rounded masses : a typical development is that at Finedon Hill (Fig. 36), where the relation of the nodules to pockets of Lower Estuarine white sand provides clear evidence of their secondary origin. Presumably in Estuarine times conditions not unlike those of the Coal Measures swamps were obtaining and in such circumstances leaching of the beds underlying the swamps might be expected. In particular, iron would be dissolved and, if later carried into a zone of stagnation and reduction, precipitated in the ferrous state. The sphaerosiderite in the Northampton Sand is thus similar in origin to that described from Coal Measures Ironstones in Yorkshire by Mr. T. Deans (1934). In other cases secondary siderite is finely granular and maybe a replacement under marine conditions as, for example, in the sideritisation of certain beds with distorted ooliths in the Lower Chamosite-Kaolinite group ,where the latter is immediately overlain by siderite mudstone (c, Plate 16, A).

Wherever the Northampton Sand crops out or has a small thickness of cover, it has suffered extensive weathering. Ferrous compounds of iron have been altered to the ferric state and the grey and grey-green colours of the original ore have given place to browns and red-browns. It is in this oxidised condition that the bed is commonly seen save in underground mines and the deepest opencast workings. In the process of weathering carbon dioxide is lost, siderite is converted to limonite or goethite and chamosite breaks down to a series of alteration products that appear to include kaolinite, goethite and possibly some silicate of ferric iron. Considerable redistribution of iron within the bed takes place in the form of limonitic crusts along bedding planes and joints. The alternation of bands of iron-rich and iron-poor material as concentric layers within a joint-bounded block gives rise to the characteristic " box-structure " so typical of the Northampton Sand. Secondary gypsum is not uncommon as a constituent of the oxidised stone.

Lower Estuarine Series. The Northampton Sand is normally overlain by the Lower Estuarine Series. These beds consist over the greater part of the area of sands, silts and clays and vary from 15-25 feet in thickness. South of Kettering and Twywell the beds are thinner and 10-15 feet is perhaps an average figure, though in the Finedon-Irthlingborough area the thickness is seldom more than 5 feet and the Series is absent over considerable areas. Across the northern part of the area, however, there is a belt, some two to three miles wide, in which the beds are reduced in thickness or cut out completely as a result of channelling by the Upper Lincolnshire Limestone. The extent of this channelled belt is discussed in more detail in the section on the Lincolnshire Limestone (see p. 222).

In the north of the area the Series consists broadly of a lower and an upper division of sands and silts with a middle division dominantly clay. At the top of the middle division there is commonly a conspicuous bed of dark grey or black carbonaceous shale referred to by Richardson and Kent (1938) as the "Coaly Bed" : it is in many places underlain by a band of sandy silt with vertical rootlets.

Variations from this standard succession are common. The beds at the base of the Series may be largely argillaceous, the black shale bed may be reduced to a few inches in thickness or be absent. Yellow-brown sands found at the top of the Series rest unconformably on the beds below and may channel into them, cutting out the black shale and resting on the grey clays below (e.g., in Short Leys Pit, near Corby). Similar marked local thickening of the upper sands also occurs much farther south, e.g., at Orton Sand Pit, where the Ironstone and the Lincolnshire Limestone are separated by 25 feet of sand of this age.

Elsewhere the beds above the black shale consist entirely of grey and brown clays. At one point in Priors Hall Pit north-east of Corby the whole of the beds below the yellow-brown sand consisted of dark grey wedge-bedded silts and siltyclays.

South and east of a line joining Kettering and Oundle the Lower Estuarine Series is almost entirely represented by light grey or almost white silts and sands. The lower massive beds of fine-grained sand rock, feebly cemented sandstone or siltstone, locally known as "ganister," have been worked as refractories in the neighbourhood of Lowick, Twywell, Islip, Thrapston, Burton Latimer, Weston Favell and Earls Barton. The upper part of the Series locally contains beds of grey clay and silty clay. The area of maximum development of the sands forms a belt with a general N.E.-S.W. trend. It is perhaps worthy of note that this belt is roughly parallel with both the southern limit of development of the Lincolnshire Limestone to the north-west of it and of the Northampton Sand to the south-east.

In the Irchester area to the south-east of the belt of maximum development of the ganister sands the coaly bed is again well developed, the general upward succession being silts 2-7 feet, coaly clays and silts 2-5 feet and bluish grey clays 2-3 feet.

Here and there, over a wide area in the southern part of the ground, there is developed a 1-2 foot bed of grey or grey-brown clay containing abundant spherulites of siderite. This sphaerosiderite band occurs 6-7 feet above the base of the Lower Estuarine Series in Cranford North Pit, 6 feet above the base at Lodge Pit, Irchester. In it the spherulites have reached a perfect form. They are up to 1.5 mm. across and so widely spaced that neighbouring individuals do not interfere with one another. They are set in a clay groundmass in which quartz, white mica and pyrite are recognisable. Macroscopic quartz grains are common and some are enclosed by the spherulites, suggesting that, as in the case of the sphaerosideritic rocks in the Northampton Sand, the siderite is of post-accumulation age.

Lincolnshire Limestone.—Lincolnshire Limestone is confined to the northern and north-western portions of the area. The southerly limit of the main mass of the formation may be taken as a line running from the neighbourhood of Maidwell, one mile west of Draughton, E.N.E. to Kettering and thence in a general N.E. direction to pass just north of Oundle. South of this line the limestone is absent, save for what may represent a local development of the basal bed, and the two Estuarine Series come together.

The succession of the Lincolnshire Limestone is incomplete and the thickness considerably less than the 120 feet developed to the north in Rutland and Lincolnshire. Two divisions can be recognised, the upper of which rests with strong unconformity on the lower. The missing part of the succession includes the characteristic band with *Acanthothyris crossi* (Walker), which has been traced over wide areas by Dr. F. B. A. Welch and Mr. G. A. Kellaway in the country between Grantham and Stamford.

The Lower Lincolnshire Limestone consists mainly of sandy limestone and rather even-grained oolites. Though worn and comminuted shell debris is widespread, in general identifiable fossils are not common. The total thickness of the sub-division is about 40 feet. At the base thin flaggy fissile representatives of the Collyweston Slate are locally present and have yielded such characteristic fossils as *Pinna cuneata* Morris and Lycett, *non* Phill., *Gervillella acuta* (J. Sow.), *Modiolus* (*Inoperna*) *plicatus* (J. Sow.) and *Phyllocheilus bentleyi* (Morris and Lycett). The slates were formerly worked in the old pits west of Kirby Lodge, to the north of Corby. They readily become decalcified and in Lower Brookfield Pit and Deene Pit north of Corby are represented by rounded masses of fissile calcareous sandstone imbedded in yellow-brown sands. In the ironstone workings at Cranford St. John and south-west of Denford, several miles south of the limit of the main area in which Lincolnshire Limestone is developed, there is a somewhat similar development of rounded masses of calcareous sandstone at the junction of the Upper and Lower Estuarine Series.

Overlying the Collyweston Beds or, where these are absent, resting directly on the Lower Estuarine Series, several feet of massive fine-grained limestone containing abundant turretted gastropods (*Nerinea*, *Nerinella*, *Ptygmatis*) are commonly developed. These are succeeded by moderately fine-grained oolitic limestones and even-grained oolites. A feature of these sandy beds of the Lower Lincolnshire Limestone is a tendency to break down through decalcification into a soft brown sand or sandstone. Beds of decalcified limestone of this type interbedded with massive limestones and oolites are well exposed in Short Leys, Deene and Priors Hall Ironstone pits near Corby. In the Cottingham-East Carlton area, where the Lower Lincolnshire Limestone has been extensively quarried, a rather distinctive lithological type consisting of moderately coarse ooliths set in a groundmass of very fine-grained ooliths first appears 8 to 10 feet above the base of the formation. In the upper beds of the Lower Lincolnshire Limestone bands of coarse oolite not unlike those of the Upper Lincolnshire Limestone are developed.

The Upper Lincolnshire Limestone is represented by some 40 feet of coarse shelly oolites known as Weldon Beds from the type locality where they have been extensively worked for building stone. Lenticular developments of hard, pale coloured, oyster-bearing limestone occur throughout the succession and are known to the quarrymen as "Weldon Rag." Between 15 and 20 feet above the base there is a prominent bed crowded with casts of lamellibranchs (*Mytilus*) and gastropods, known as the "Roach Bed." Throughout the Weldon Beds small Terebratulids and Rhynchonellids ("*Terebratula*" *weldonensis* Muir-Wood M.S., and "*Rhychonella*" *barnackensis* Muir-Wood M.S.) are common: also corals and echinoids such as *Trochotiara depressa* (Ag.) and *Stomechinus germinans* (Phillips) Wright occur. These beds are visible in numerous exposures round Weldon, at Stanion and near Brigstock and further west at Little Oakley, Pipewell and Wilbarston.

The Upper Lincolnshire Limestone rests on the Lower with strong unconformity. Commonly it is deposited in channels with its base cutting through Lower Lincolnshire Limestone and Lower Estuarine Series to rest directly on Northampton Sand. Occasionally the top beds of the Northampton Sand have also been removed by intra-Jurassic erosion, but this appears to have been rare.

Channelling of the Lower Lincolnshire Limestone and Lower Estuarine beds by Upper Lincolnshire Limestone is concentrated in a belt from 2 to 3 miles wide, running roughly parallel to the southern limit of the Lincolnshire Limestone and 1 to 2 miles north of it. The belt extends in a general E.-W. direction from

Pipewell, 2 miles south-east of Wilbarston, to the Oakleys ; thence north-eastwards through Weldon and Stanion in the direction of Apethorpe and Woodnewton. Within this belt the individual channels, which may be up to half a mile across and three miles in length, trend between E.-W. and N.E.-S.W. Excellent examples of the channelling may be seen in the ironstone pits south of Corby. There seems little doubt that it is a result of submarine erosion through tidal or current action.

Within the area under discussion the Upper Lincolnshire Limestone is largely, but not entirely, confined to the channelled belt. Nowhere in this area is a thick development of Upper Lincolnshire Limestone superimposed on a thick development of Lower Lincolnshire Limestone. The maximum thickness of each subdivision—about 40 feet—is very nearly the maximum thickness of Lincolnshire Limestone developed at any point (see Plate 16, B).

Upper Estuarine Series. In the northern and western parts of the district (north-west of a line joining Kettering and Oundle) the Upper Estuarine beds are commonly between 40 and 45 feet thick. Only locally does the thickness fall below 35 feet. A general three-fold division can be recognised :—

	Feet
Green, greenish grey and grey clays	8–12
Limestone or marly limestone with abundant oysters and *Burmirhynchia*	3–5
Light and dark grey and greenish grey clays. Occasional thin fissile limestone partings in upper part. Light grey clays towards base. Nodular impersistent band of ironstone at base	25–32

The lower beds in the succession are exposed in several of the ironstone pits round Corby. At Priors Hall Pit all the beds up to the limestone are visible. The basal beds are unconformable to the rocks below, the nodular ironstone band resting in some places on Lower, in others on Upper Lincolnshire Limestone. At the eastern end of Short Leys Pit 8-9 feet of intensely black shale with the ironstone band locally present at the base occupies a pocket or channel in the Lower Lincolnshire Limestone, which is locally reduced to one foot in thickness.

South of the Kettering-Oundle line the Upper Estuarine beds are thinner and in the Cranford-Twywell-Islip area the average thickness is about 20 feet. The greater part of this thinning takes place in the lower subdivision, which is reduced to less than 10 feet in thickness. The limestone is thicker and more massive in the south than in the north, while the overlying clays remain approximately constant in thickness or are slightly thinner in the south.

In the southern area the limestone can usually be divided into three divisions : a lower of unconsolidated or feebly cemented *Ostrea*-bed, usually 3 feet thick, but locally as at Burton Latimer 7-8 feet ; a middle division of limestone consisting of massive coarse detrital limestone with a gritty irregular base, strongly cemented, with bands of calcite mudstone and soft marl, up to 5 feet in thickness ; and an upper division of siltstones with bands of white, nodular weathering, marly limestone 2-4 feet thick. The middle division is well developed in the Doddington area, where it has been quarried for local building stone. The upper division is well exposed in the old quarry face south of Finedon.

In the Finedon-Irthlingborough neighbourhood also the lower subdivision is absent and the *Ostrea*-bed of the Estuarine Limestone rests directly on the Lower Estuarine Series.

Great Oolite Limestone. The Great Oolite Limestone is in general persistent in lithology and thickness throughout the area, and is visible in many good exposures. In the north, where the Lincolnshire Limestone is present and the Upper Estuarine beds are thick, the Great Oolite Limestone is too far above the top of the Northampton Sand to be exposed in any of the ironstone workings. In the south, however, where Lincolnshire Limestone is absent and the Upper Estuarine Series thin, the Great Oolite Limestone has commonly to be removed in the over-burden of the deeper open-cast workings. In addition the limestone is exposed in numerous pits, where it has been worked for use as a furnace flux, for lime, for cement manufacture and for rough stonework.

In thickness the Great Oolite Limestone ranges from 15-25 feet. In available sections the limestone has usually weathered to creamy white or deep cream with the uppermost beds a medium brown in the Irchester area. At depth, however, the unweathered stone is a grey to bluish-grey tint and this survives in a few of the more compact rock types in deeper quarries.

The prevailing lithological types are fine-grained non-oolitic compact rocks forming massive beds or occurring as bands 6-9 inches thick interbedded with marl, fine-grained, sparingly oolitic to dominantly oolitic freestones, massive rubbly unbedded and frequently shelly beds and coarse detrital, even bedded or strongly current bedded, flaggy to massive limestones.

In the south the marl with limestone occurs principally in the bottom 6 feet and locally in the middle of the formation. The fine-grained non-oolitic beds occur persistently above the lower marly series, and the detrital limestone, usually with the highest content of calcium carbonate, in the middle, e.g., in the Twywell-Islip area, near Pilton, and in the Finedon-Irthlingborough district. Oolitic and rubbly non-oolitic beds are developed at various horizons. Thin partings of fibrous calcite and gypsum are of common occurrence. Examination by Mr. P. A. Sabine of samples of Great Oolite Limestone has shown that the proportion of material insoluble in acid (mainly quartz) ranges from 3-10 per cent, but the percentage was found to vary too much to be used for the correlation of individual beds.

The Great Oolite Limestone is highly fossiliferous and has yielded such species as *Kallirhynchia sharpi* Muir-Wood, *Epithyris oxonica* Arkell and vars., *Digonella digonoides* (S. S. Buckman), *Stiphrothyris capillata* Arkell, *Burmirhynchia* spp., *Trigonia phillipsi* Morris and Lycett and *Trigonia impressa* Broderip, abundant *Ostrea hebridica* Forbes, "*Eocallista*" *loweana* (Morris and Lycett) and *Clypeus mülleri* Wright. At the base of the Series a 2-3 foot band of rubbly rather argillaceous limestone, often interbedded with grey and brown clays, crowded with *Kallirhynchia sharpi*, is widely developed. Locally some five feet above the base of the limestone there is a prominent *Trigonia*-bed. Between 8 and 12 feet above the base a thin band (9 inches) containing abundant specimens of *Epithyris oxonica* and *Digonella digonoides* is exposed in the Twywell and Cranford ironstone pits.

Great Oolite Clay.—The Great Oolite Limestone is overlain by a succession of vari-coloured clays—grey, blue-grey, green, reddish and purple. Near the base there is frequently developed a thin nodular band of clay ironstone. Good sections of these beds are rarely seen. Where exposed, as in Twywell Limestone Pit or in Bridle Limestone Pit near Islip, the face rapidly becomes slipped and obscured. These clays form, however, a readily mappable band, separating Cornbrash from Great Oolite Limestone and recognisable by the brightly coloured clays on ploughed land. A haematitic red colour is particularly distinctive. The normal thickness of Great Oolite Clay is 12-20 feet, but at outcrop this is frequently reduced as a result of cambering.

Cornbrash. The Cornbrash is a reddish-brown limestone, often extremely shelly and with a well developed flaggy habit. The normal thickness is 5-6 feet with a maximum of about 8 feet. In some places it is much thinner and may be represented by less than 1 foot of limestone which is locally ferruginous, as, for example, west of Apethorpe and south of Benefield. Both Upper and Lower Cornbrash are present in the area, the latter characterised by *Cererithyris intermedia* (J. Sow.), *Obovothyris obovata* (J. Sow.), *Meleagrinella echinata* (W. Smith) and *Clydoniceras*, the former by *Microthyridina lagenalis* (Schlotheim) and *sublagenalis* (Davidson), *Lopha marshii* (J. Sow), *Ostrea undosa* Phillips, and Macrocephaloid ammonites. Douglas and Arkell (1932) have described in detail sections near Thrapston and Islip. Despite its small thickness the Cornbrash gives rise to extensive outcrops either forming high ground or capping spurs which project from beneath the overlying Oxford Clay.

Oxford Clay and Kellaways Beds. Although the Oxford Clay is extensively developed in the eastern part of the area under consideration it is largely covered by drift and very rarely exposed. In places a development of fine sand or silt, 10-20 feet thick, near the base, has been mapped as the Kellaways Sand.

Fossils are rare save for a small species of *Nuculoma* and occasional belemnites.

V. TECTONIC STRUCTURE

The major structural pattern of the area is relatively simple. The normal inclination of the strata is eastwards or east-south-eastwards at a dip of less than half a degree. As a result of this dip Northampton Sand, which caps the high ground in the western part of the area at an altitude of 4-500 feet, is carried down to valley floor level or below at less than 100 feet O.D. in the east (see structure contours, Plate 15). Consequently successively higher beds appear as one goes from west to east across the area. Over much of the southern portion the disposition of the beds has been modified so extensively by superficial movements that few traces of original tectonic structures can be recognised.

The general easterly dip is disturbed by a series of gentle folds with trends between N.W.-S.E. and E.-W. The most important of these is the syncline which extends from the neighbourhood of Stoke Albany south-eastwards through Pipewell and then swings into an E. by S. and W. by N. course to the south of the Oakleys in the direction of Brigstock. This may be called the Stoke Albany-Brigstock syncline (Plate 15). It gives rise to a belt through which the ironstone is under deep cover and where so far no working of the ore has been attempted. The maximum dip on the flanks of the syncline is of the order of 2°-3°.

North-east of the Stoke Albany end of this syncline (bounded on the south-west by the Pipewell Fault) there is a gentle complementary anticline parallel to it with its axis between Wilbarston and East Carlton. Farther to the north-east and with the same general trend is the Rockingham syncline running from Rockingham Park in a south-easterly direction through the northern part of Thoroughsale Wood. South-east of the Rockingham syncline, but approximately on the continuation of its axis, a syncline runs under South Wood, west-north-west of Stanion. North-east of the Rockingham syncline the Corby anticline has a similar trend. On the north-eastern flank of this fold five faults with a general N.W.-S.E. direction and with throws of 10 to 20 feet drop the beds down successively towards the north-east.

There is, thus, in the north-west part of the area a series of gentle N.W.-S.E. anticlines and synclines with associated small-scale faulting.

On the axis of the Rockingham and South Wood synclines and to the south-east of them a trough-faulted belt runs from south of Stanion to Aldwinkle. The width of the trough increases from less than a quarter of a mile in the north-west to nearly a mile in the south-east. The displacement of the beds within the trough relative to those on either side is of the order of 40-60 feet.

In the southern part of the area faults with a general trend N. of W.—S. of E., as for example west of Little Addington and between Walgrave and Orlingbury form part of the same general structural pattern.

There are also a few structures with an E.N.E.-W.S.W. trend. For example an anticline faulted at its northern end runs from north of Draughton, through Orton, in the direction of Rushton. Over the crest of this the Northampton Sand has been removed between Rothwell 1½ miles south-east of Desborough, and Glendon, and boulder clay rests directly on the Upper Lias. A fault passing through Weekley, Boughton Park and Old Head Wood with southerly downthrow has a similar trend. The fault which runs in an E.N.E.-W.S.W. direction through Stoke Albany and Wilbarston to the southern edge of East Carlton Park is probably associated with the same group of structures: but its effect has possibly been intensified by superficial movements along the Inferior Oolite escarpment.

A point of interest regarding the faulting in this area is its association with a considerable amount of terminal bending. In numerous instances boreholes have shown that the actual throw on a fault plane is relatively small, while the displacement of the general level of beds on either side of the fault is considerable. This tendency to bend rather than to break appears to be characteristic of the Jurassic rocks of the Ironstone Field.

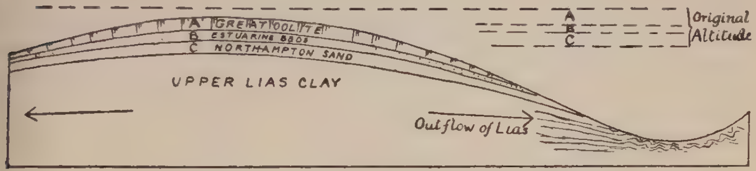
VI. SUPERFICIAL STRUCTURES

The surface expression of the original structures of deep-seated origin has been extensively modified by relatively recent superficial movements resulting from the differential flowage of clay under load. These movements have accompanied the development of the valley system and appear to be entirely connected with the present cycle of erosion. Their distribution and origin have been discussed by Hollingworth, Taylor and Kellaway (1944).

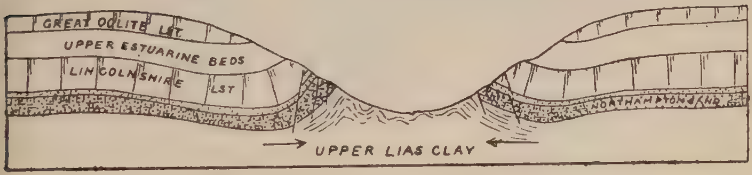
Cambers. The term cambering has been applied to a process whereby outcropping or near-surface strata have been lowered towards the valleys. This process has given rise to an arched or saddle-like disposition of the Northampton Sand and higher beds along spurs and ridges (Fig. 37 (a)). It is widespread in the area wherever erosion has cut down to the Lias Clay and is attributed to the valleywood outflow of the soft and plastic clay below the base of the Northampton Sand. By these means a vertical lowering of the order of 100 feet or more has commonly occurred. Some evidence of the internal movement in the Lias is afforded by the occurrence of "clay pebble beds" beneath cambered slopes, as, for example, in the clay pit adjoining Wellingborough Iron Works (Hollingworth, Taylor and Kellaway, 1944, p. 11).

Two principal varieties of cambers are recognised. In multi-formational cambers of the type present at intervals along the escarpment of the Inferior Oolite overlooking the Welland valley all the rocks above the Upper Lias have moved *en masse*. Composite cambers such as are produced on both sides of the Nene valley near Thrapston result from movement not only in the clays of the Upper Lias, but also those of the Upper Estuarine Series and Great Oolite Clay.

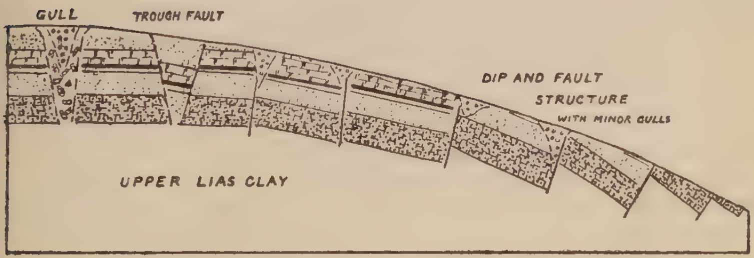
Gulls. The outward flowage of clay in the process of cambering gives rise to tensional stress in the overlying beds. One method of accommodation to these stresses in massive competent strata



(a) Camber in originally horizontal strata.



(b) Valley bulge in originally horizontal beds.



(c) Structures in a cambered sheet.

FIG. 37.—DIAGRAMMATIC SECTIONS TO SHOW SUPERFICIAL STRUCTURES.

is by the process of gulling, in which steeply inclined fissures or joints, normally trending parallel to the surface contours, have been opened out and wholly or partly filled with material from above (Fig. 37 (c)). The infilling may consist of sand, clay, rock or drift and the upward succession in the gull commonly reproduces that of the walls and former cover. Not infrequently deposits that have in general been removed by erosion in the immediate neighbourhood are preserved in gulls, showing that these structures are of considerable antiquity.

Gulls show considerable variation in form. At Longhills Pit, east of Corby, long narrow, parallel-sided gulls in the Lincolnshire Limestone represent widened joints filled with boulder clay. At Pitsford Ironstone Pit, north of Northampton, a magnificent series of gulls containing boulder clay and estuarine silts have been let down into the Northampton Sand. In Marsh's Pit on the west side of Harpers Brook, north-west of Islip, high Upper Estuarine beds and Great Oolite Limestone are let down into Lower Estuarine and low Upper Estuarine beds in a series of trough-fault gulls. Two of these troughs are developed over the crest of small anticlinal rolls in the ironstone : it is probable that the arching and gulling were broadly contemporaneous and part of the general movement of the camber.

Dip-and-Fault Structure. A second method of adjustment of strata to the tensional stresses arising from cambering is by the formation of dip-and-fault structure (Fig. 37 (c)). This is a consequence of a series of parallel fractures developing with rotation of the inter-fault blocks into a position with a downhill dip greater than the general inclination of the camber.

Excellent examples of dip-and-fault structure can be seen near Wakerley and Geeston, north of the area under consideration. Within our area, however, it is rather poorly represented in existing exposures, e.g., at Pitsford, though a good example was formerly visible in a temporary section at the eastern end of Cowthick Ironstone Pit on the flanks of a small valley. Here the faults had only a few feet throw and the valleyward dip of the inter-fault blocks was about 30°.

Bulges. Valley bulges comprise a variety of displacements of the strata occupying the floors or lower slopes of valleys. They may have a simple anticlinal form (Fig. 37 (b)) or occur as a series of discontinuous elongated domes. Faulted margins to the disturbed belt may give rise to a steep-sided horst-like structure.

The intimate association of these disturbances with the present valley system leaves no room for doubt as to their superficial origin. They are evidently a consequence of the differential unloading of the plastic Lias Clay as a result of normal subaerial denudation. As the down-cutting of the streams proceeded, the excess load on either side of a valley caused a flowage of clay towards the area of minimum load with consequent forcing up of the rocks in the valley bottom. In some cases the bulge does not occupy the bottom of the valley but occurs on the up-dip side of it. This is interpreted as a consequence of lateral migration of the stream down dip subsequent to the bulging.

Six-inch mapping combined with borehole data has revealed the presence of bulges in many of the valleys of our area. These structures do not lend themselves readily to demonstration in the field save where one of them is encountered in the rapidly advancing face of an ironstone working. Excellent sections, now no longer visible, were formerly exposed at Priors Hall and Cowthick Pits in the Corby neighbourhood and farther to the south in the workings at Cranford.

Sags.—The outflow of Lias in the process of formation of a valley bulge necessarily implies some vertical lowering of the strata above the Lias in the region of outflow (Fig. 37 (a)). For this reason synclinal downfolds or sags are frequently developed on the flanks of valley bulges (Fig. 37 (b)) and are usually elongated in a parallel direction.

This type of sag is exemplified by the synclinal structure flanking a valley bulge on the south-west bank of Harpers Brook, south of Sudborough. Here the downwarped area of ironstone surrounded on three sides by Lowick and Sudborough Ironstone quarries has been left unworked on account of its waterlogged nature.

A second type of sag occurs where the valleyward outflow of Lias forming a camber has been strongly localised in consequence of some predisposing structural or topographical factor. A good example of the former is the synclinal area west of Irthlingborough, where a deep downfold on the south side of an east-west structural fault appears to be largely due to superficial movement resulting from outflow of Lias from an area that was delimited at depth by the fault plane. The structure is well exposed in the disused quarry of the Premier Cement Co. at Irthlingborough. In other cases corrie-like structural half-basins open on the valleyward side are developed on cambered slopes as on the east side of the Nene valley to the west of Irchester.

VII. GLACIAL AND POST-GLACIAL DEPOSITS

By comparison with the Avon-Severn drainage to the west and the Great Ouse basin to the east the drifts of the Nene catchment area have been subject to little intensive study. Apart from the records of mammalian bones from the river gravels and some important temporary sections described by Beeby Thompson, the literature of the Northamptonshire drifts is very slight. Thompson has given a brief general account in *Geology in the Field* (1910).

Within the area dealt with then the following divisions can be tentatively made :

Post-Glacial	River Terraces and alluvium.
Chalky Boulder Clay Glaciation	Chalky boulder clay with associated gravels.
pre-Chalky Boulder Clay Glaciation	Mid-Glacial Gravels. Lower Boulder clay.
pre-Glacial	Sands and Gravels.

The pre-Glacial Sands and Gravels are characterised by material that is wholly of local origin. They are best developed to the south and south-west of our area, where they occupy low ground about Collingtree and Milton to the south of Northampton (visited in 1891). Here they are predominantly sands, and it has been suggested by Beeby Thompson that they belong to an early river system dating from a time when the western branch of the Nene flowed south-east to join the Ouse above Bedford.

Gravels of wholly local origin are recognisable beneath the oldest boulder clay, e.g., two miles south of Irchester, where an 8-foot section is made up entirely of local limestone and ironstone.

A new feature of the drifts of the district is the recognition of the *Lower Boulder Clay*, which is free from chalk and flint and characterised by Jurassic and Bunter erratics, suggestive of derivation from northerly sources along a route lying west of the chalk wolds of Lincolnshire. South of the latitude of Kettering this boulder clay has been mapped for many miles—principally as a margin to the dissected chalky boulder clay of the (main drift-covered) plateaux. In consequence of the absence of chalk and flint this clay is, unless checked by augering, liable to be included with the solid clays when overlying them. It is readily recognisable, however, in sections and in auger bores as a stiff dark grey to greenish grey clay with abundance of quartzose gritty material and fragments of Jurassic limestone and ironstone. Bunter quartzites, and a remarkably ubiquitous content of *Serpula* fragments are equally characteristic.

The distribution of the clay suggests that it tends to thicken into the hollows in the pre-glacial surface and thin out beneath chalky boulder clay on the higher ground, so that over the latter the chalky boulder clay in many places rests directly on the solid formations.

Related gravels, here termed *mid-Glacial* in a local sense, have a similar " local + Bunter " pebble content. They may well represent outwash in some cases, e.g., at Brixworth, and in others (e.g., in the Ise valley above Kettering) old valley gravels.

There are good sections in coarse, torrentially bedded, boulder gravels, not related to a valley system, that occur beneath chalky boulder clay in the ironstone pits north of Brixworth.

Here the lower boulder clay can be seen below the gravels under favourable conditions. Beyond the limit of the gravels the lower clay is usually visible between the chalky boulder clay and the Northampton Sand. Old pits showing these gravels were visited by the Association in 1891.

Outcrops of gravels between the two boulder clays have been mapped in a few localities. Those along the Ise Valley referred to above are in most occurrences preserved as outliers on the ends of short spurs on the valley sides and resting on Lias clay. Higher on the valley side both the lower non-chalky and chalky boulder clay have been mapped with no intervening gravels. The gravels on the lower slopes are interpreted as representing a fluvial, valley-bottom deposit formed during the interval between the two boulder clays and surviving both burial by chalky boulder clay and the post-glacial erosion and deepening of the old valley.

The *Chalky Boulder Clay* ranges from a dark grey clay to a pale bluish grey marly clay depending on the content of comminuted chalk. It occupies much of the plateau-like high ground, filling in considerable unequalities in the underlying strata. In deeper depressions in the surface of the solid rocks it may reach thicknesses of 100 feet or more. Generally there is a tendency for chalk and flint to increase in amount from below upwards. Towards the top, or capping the boulder clay, patches of chalky gravel occur. In general there is little to suggest that these gravels are definitely outwash deposits, though their intimate connexion with the boulder clay is indubitable.

There is little or no definite evidence for glaciation of the area by an ice sheet or sheets later than that which deposited the main chalky boulder clay. Certain spreads of gravelly chalky drift occupying much of the slope of the Nene Valley east of Doddington might be regarded as later than the main boulder clay ; but their relations to other drifts are not known.

The gravels and sands at Brigstock visited by the Association in 1895 and in 1937 (Beeby's Sand Pit, Richardson and Kent, 1938) possibly represent the oldest gravels of local origin. The overlying boulder clay in its upper part contains chalk, Bunter pebbles and large septarian nodules. The lowest 10 feet or so, however, carries relatively few pebbles consisting of Bunter quartzite and rolled ironstone and limestone, together with serpulae and pockets of gravelly sand. The upper part is undoubted Chalky Boulder Clay, while the lower appears to consist of the lower pre-Chalky Boulder Clay. Where material generally resembling the latter type contains an occasional fragment of flint and chalk it may perhaps be interpreted as consisting largely of lower boulder clay resorted and redeposited when the chalky boulder clay was formed.

A series of river terraces mark the most recent stages in the geological history of the area. Along the Nene Valley river gravels at three different levels can be recognised in addition to the alluvium of the present flood plain. The highest terrace, which is only locally preserved, at Aldwinkle, near Oundle and south of Warmington, occurs at a height of 45-50 feet above present river level. Its direct relationship to the chalky boulder clay is nowhere seen, but it lies well below the level of the boulder clay base. The regular nature of this base and the fact that there is little trace of glacial drift preserved at lower levels could be taken to indicate that the main erosion of the Nene valley and consequently the formation of the terraces is of post-glacial age. The possibility that erosion has completely removed boulder clay from the sides of an old valley while leaving some of the gravel deposits cannot, however, be excluded.

A second period of aggradation following renewed down-cutting, is marked by the middle terrace 25 feet or so above the present flood-plain. Remnants of this old valley floor are preserved at intervals from Thrapston downstream to Wansford and an 18-feet section in the well-rolled current-bedded gravels is visible at Aldwinkle. This terrace is present in the lower part of the Harper's Brook valley, but is not preserved in the Ise valley.

The low terrace, which is widespread along both Ise and Nene, forms a gently sloping shelf rising to 10 feet or so above present flood plain level. The margins of this terrace are frequently obscured by an extensive downwash of sandy loam from the valley sides. The gravels of the low terrace are continuous with those below the alluvial flood plain, representing an infilling of a broad valley cut below present stream level. They have been worked beneath the alluvial deposits at Billing, Irthlingborough, Thrapston and Oundle. Evidently they date from a period of lower base level than that of today. This period probably corresponds to the formation of the buried channel of the river below Peterborough.

The most recent deposits of the River Nene are the alluvial clays of the present flood plain, which occupy broad meander belts cut, in large part, in the low terrace and buried channel gravels.

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KETTERING FIELD MEETING

June 7th-10th, 1946.

Report by the Directors : S. E. Hollingworth, M.A., D.Sc., F.G.S., and J. H. Taylor, M.A., Ph.D., F.G.S.

Friday, June 7th

THE party, numbering 23 (approximately the capacity of the bus hired for the week-end), assembled after dinner in a room reserved at the headquarters, the George Hotel, where the President welcomed visitors from the Kettering Natural History Society and Field Club. As most of the members had acquired advance copies of the pamphlet prepared for the meeting, Dr. Taylor was asked to supplement this with a talk on the history of the local ironstone industry and a lively discussion followed in which the visitors joined.

The President also indicated that the party would be visiting many working quarries not normally accessible, and that the best thanks of the Association were due to the Directors of the operating companies for these facilities.

Saturday, June 8th

BRIXWORTH, PITSFORD, EARLS BARTON, IRCHESTER AND IRTHLINGBOROUGH

Early in the journey to Brixworth attention was drawn to the characteristic smooth outline of the long spurs of Upper Lias capped by strongly cambered Northampton Sand. Farther on, the undissected boulder clay plateau between the Ise and the Maidwell branch of the Nene was crossed. Shallow ironstone pits of the Lamport Ironstone Co. were passed near Scaldwell and Lamport en route to the Clay Cross Co.'s pit a little east of the Market Harborough road, a mile north of Brixworth. Here oxidised ironstone of the Main Oolitic Group is capped by a foot or two of sandy oolite (Upper Siderite Mudstone-Limestone Group)[1] and a considerable thickness of glacial deposits. These latter include representatives of lower or pre-chalky boulder clay and its associated chalk-free, and flint-free gravels. In these, local rocks with much Triassic quartzite pebbly material are the principal boulders. Their mutual relations have been disturbed, presumably during the passage of the ice which laid down the overlying chalky boulder clay.

A brief halt was made at Brixworth Church—a fine example of early Saxon work. The basal portion of the tower incorporates many roughly dressed boulders of igneous rocks, including Charnwood pre-Cambrian types presumably derived from the deposits of the pre-chalky boulder clay glaciation.

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[1] For details of succession see Hollingworth and Taylor, 1946.

At the Upper Lias clay pit of the disused Hamson's brickworks, 1 mile south of Brixworth, the breaking up of the capping of Northampton Sand associated with pronounced cambering was studied. The pit is at the southern end of a broad spur on the side of the valley of the Pitsford Brook (Hollingworth, Taylor and Kellaway, 1944, p. 5, Fig. 1). Lateral spreading has resulted in longitudinal 'faults' parallel to the axis of the spur accompanied by outward dips of up to 40 degrees in the inter-fault blocks. Fossils collected from the Lower Siderite Mudstone-Limestone Group included a Terebratulid that is considered by Dr. Muir-Wood to represent a new genus and species.

The ironside quarry of the Pitsford Ironstone Co., on the south side of the ridge a mile south-west of Pitsford, provides excellent examples of the gulling of Lower Estuarine silts into the Northampton Sand. The latter consists of up to 25 feet of partly decalcified and oxidised sandy sideritic limestones of the Upper Siderite Mudstone-Limestone Group resting on 6-11 feet of workable ironstone. A detailed section along the face of this pit has been published (Hollingworth, Taylor and Kellaway, 1944, Plate II, 2 and pp. 11-12). The ironstone is mostly oxidised stone of the Main Oolitic Group with some green carbonate stone in the deeper part of the pit. A massive top bed of resorted ironstone and shelly material yielded the following forms, *Montlivaltia* sp.,[1] *Camptonectes laminatus* (J. Sow), *Entolium demissum* (Phillips), *Lima* (*Plagiostoma*) *northamptonensis* Cox, *Parallelodon hirsonensis* (d'Archaic), *Pseudolimea interstincta* (Phillips), *Pseudotrapezeum acutangulum* (Phillips), *Tancredia axiniformis* (Phillips), *Trigonia V-costata* Lycett, *Variamussium pumilum* (Lamarck) and *Velata abjecta* (Phillips). From the massive oolite below the shelly bed *Ceratomya bajociana* (d'Orbigny) was collected.

The beds above are sandy sideritic limestones, massive to flaggy blue-hearted in the lower part, with occasional seams or layers of pellets of siderite mudstone. In the upper part decalcification is widespread, and soft, brown sandstones and sandy limonitic beds, representing oxidised and decalcified sideritic rocks, are typical. Similarly weathered material characterises the strata marginal to the gulls. An interesting feature of the section is the pronounced local erosion of the lower beds and infilling of channels with a curiously mottled sandy oolite (Hollingworth and Taylor, 1946, Plate 16A and p. 217).

Lunch was taken at Earls Barton and most of the party availed themselves of the opportunity of visiting the church, the Saxon tower of which is one of the finest in the country.

On the north-east side of the village the working quarry of the Earls Barton Silica Sand Co. was examined by permission of Mr.

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[1] The Directors are greatly indebted to Dr. H. M. Muir-Wood and Dr. L. R. Cox for lists of fossils collected by or presented to them during the meeting.

T. H. Partridge. Here an 8 to 10-foot face of refractory sands and silts of the Lower Estuarine Series is worked after removal of an overburden of up to 10 feet or so of Upper Estuarine beds and boulder clay.

It was pointed out that the ferruginous sands exposed between ironstone and Lower Estuarine silts at the entrance to the pit are not present in the main workings. They represent the eastern limit of the development of the calcareous and ferruginous beds of the western facies of the Upper Siderite Mudstone-Limestone Group, which consists of 12 feet of sandy sideritic limestones barely a mile to the north-west.

A generalised section of the working face is as follows :—

	Ft.	Ins.
Boulder Clay		
Ochreous to grey chalky boulder clay with clay loam soil up to ...	5	0
Upper Estuarine Series		
Upper Estuarine Limestone. Cream coloured, marly clay with two 3–5-in. bands of hard coarse detrital limestone	1	9
Gray, laminated limestone, white, unevenly bedded limestone and sandy, ferruginous limestone with shelly base... ...	1	8
Buff to grey, silty marl with abundant *Ostrea hebridica* Forbes and *Burmirhynchia* sp.	1	0
Grey silt	1	0
Green to grey clay with crushed, thin-walled lamellibranchs and rare nodules of dense limonite	1	0
Grey silts ... ... 6 in. to	1	6
Dark greenish grey clay	0	9
Grey to black silt ... ... up to	0	3
Grey-white silt and silty sand (a) ... ... 2 ft. 0 in. to	2	9
Grey-black carbonaceous silt (b)	1	0
White sand with vertical rootlet markings (c) 6 ft. 6 in. to	7	6
Pale grey clay	0	1
Grey-white sand (d)	0	6
Grey silts and clayey silts resting on Ironstone	1	7

From fallen slabs of Upper Estuarine Limestone good specimens of *Acrosalenia pustulata* Forbes with spines in place were collected.

Mr. L. N. Wilson gave a lucid account of the properties, processing, and uses of the sands and silts as refractory material for furnace linings. The beds a–d are mixed in varying proportions according to the particular requirements of the job.

From Earls Barton the route lay eastward across the Doddington-Pytchley axis, on the crest of which the Northampton Sand is thin or absent (Hollingworth and Taylor, 1946, p. 210), and beyond the Nene valley to the Lodge Quarry of the Irchester Ironstone Co. Here the party was received by Mr. W. Wolf, Manager, representing the Cargo Fleet Iron Co., who indicated the principal points of interest in the working of a deep pit of this type with up to 60 feet of overburden, and answered a number of questions.

The sections in this quarry (Plate 17, A) range from the base of the ironstone to near the top of the Great Oolite Limestone and exhibit many interesting features. The ironstone face provides excellent examples of the eastern facies of the succession in the Northampton Sand. At the western end of the pit oxidised oolitic chamositic mudstones of the Upper Chamosite-Kaolinite Group rest on a highly irregular surface of the underlying groups ranging from high up in the Upper Siderite Mudstone-Limestone Group which may be 6 feet or exceptionally 8 feet thick to well down in the Main Oolitic Group. The shelly oolite at the top of the main Oolitic Group forms a persistent massive bed 2-3 feet thick. In the central part of the northern face of the pit north-south fissures in the ironstone are occupied by white aluminous material usually referred to as allophane, but which includes other minerals also. The occurrence of this material on the scale seen in this part of the pit is exceptional and it is probably related to the ground water conditions associated with a striking synclinal or basin-like 'sag' that is visible in section in the ironstone and overlying beds of the western half of the northern face. The structure is thought to be of superficial origin and due to selective outflow of the underlying Lias towards the Nene valley.

Tetrarhynchia[1] and *Ceratomya bajociana* (d'Orbigny) were collected from the ironstone.

In the Lower Estuarine Beds the white sands so well developed at Earls Barton are feebly represented and carbonaceous to coaly silty clays are a prominent feature of this formation, which hereabouts appears to grade downwards into the chamositic group of streaky sandy oolitic shales and mudstones (possibly as the result of secondary changes).

The solid limestone beds of the Upper Estuarine Limestone are not so well developed as at Earls Barton ; but the *Ostrea* shell-bed at the base has thickened to about 3 feet. The dominantly green clays above the limestone are well exposed along the whole of the deeper part of the pit and almost the full thickness of the Great Oolite Limestone is present in the central part of the 'sag' in the northern face. The fauna of this limestone includes the following species collected during this visit :—

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[1] Dr. H. M. Muir-Wood has very kindly supplied the following important note based mainly on material collected during the meeting :

"A rapid survey of the Brachiopods of the Northamptonshire Ironstone of the Kettering district has shown that they are not identical with Cotteswold forms, though often so identified.

"The commonest Ironstone Rhynchonellid, recorded as *Rhynchonelloidea subangulata* (Hollingworth and Taylor, 1946, p. 216) is superficially similar to the Pea Grit, *murchisoni* Zone, species in external form and ornament, but the costae do not extend to the umbo in the Northamptonshire specimens, and the internal structure, examined by means of transverse sections, is that of the genus *Tetrarhynchia* S. S. Buckman of which it is a new series. The species of *Capillirhynchia* occurring near Kettering (Richardson and Kent, 1938, p. 72) is smaller, less convex and the ornament less advanced than that of *Capillirhynchia wrightii* (Dav.) from the Pea Grit, and it should be described as a new series. A third ironstone, Rhynchonellid, usually identified as *Homeorhynchia cynocephala* (Richard), is again not identical in size and form with the *scissum* species.

"The Terebratulids from the Northamptonshire Ironstone require careful study of internal structure before they can be assigned to any genus. The specimens collected on the Kettering excursion belong to new species and possibly to new genera. The affinities of these forms appear to be with the Dogger species of Yorkshire rather than with the Lower Inferior Oolite of the Cotteswolds."

Burmirhynchia occidentalis S. S. Buckman, *B. polystema* S. S. Buckman, *B. tumida* S. S. Buckman, *B. vagans* S. S. Buckman, *Epithyris oxonica* Arkell, *E. oxonica* var. *alta* Arkell, *Kallirhynchia sharpi* Muir-Wood and vars., *Stiphrothyris capillata* Arkell, '*Terebratula*' cf. *circumdata*, E. E. Deslongchamps, *T.* spp. nov., *Anisocardia islipensis* (Lycett), *A. truncata* (Morris), *Camptonectes* (*Camptochlamys*) *obscurus* (J. Sow.), *Mactromya varicosa* (J. Sow.), *Modiolus imbricatus* (J. Sow.), *Ostrea subrugulosa* Morris and Lycett, *Parallelodon hirsonensis* (d'Archaic) and *Velata sublaevis* (Laube).

After tea at Wellingborough the old quarries that formerly yielded clay and limestone for cement manufacture at the Premier Cement Co.'s Works at the west end of Irthlingborough, were visited. The Upper Lias in the old clay pit is not well exposed, but in the north-western corner an east-west fault with a downthrow north of about 14 feet brings in the Northampton Sand on the northern side of the pit. A minor feature of interest is the crumpling and bulging up of the Lias adjacent to the fault-plane. The succession in the Northampton Sand is as follows :—

	Ft.	Ins.
Northampton Sand		
Soil and ironstone rubble	2	0
Brown, weathered oolitic chamosite mudstone	6	0
Massive, brown oolitic ironstone, spheroidally weathering blocks	3	6
Soft, brown oolite (matrix partly chamositic ?)	1	0
Brown (limonitised), sideritic siltstones	4	0
Bluish-grey clay, a thin band, but fairly persistent	0	2
Brown siltstones and silt with phosphatic and calcareous nodules near the base	3	9
Upper Lias		
Bluish-grey clay ... ... up to	10	0

Here, as in other sections of the formation in this neighbourhood, the chamositic group is well developed and the Upper Siderite Mudstone-Limestone Group as well as the upper part of the main Oolitic Group is usually cut out by intra-formational erosion. Many interesting sections showing the relations of these beds are visible in the neighbouring underground workings of Messrs. Richard Thomas and Baldwins's Irthlingborough Mine.

Northerly dip into an east-west syncline to the north of the clay pit brings down the Great Oolite Limestone of the main limestone quarry. A detailed section of this formation has been given by Richardson and Kent (1938, p. 67). A striking structural feature, well exposed in plan and in section at the north end of the quarry, is the pronounced squeezing or bulging up of lower beds along the line of an east-west fault. Although the net downthrow south across the disturbance is about 20 feet the bulging and squeezing up of Estuarine Beds, Ironstone and Lias along the line of the fault brings up the last named in the core of a sharp fold, to the level of the Cornbrash on the downthrow side of the fault. The fault itself is traceable for a mile and is probably a tectonic break older than the valley systems ; but it seems possible that the intense disturbance along it is a later effect associated with superficial movements of the Lias Clay towards the Nene valley. The latter movements are clearly indicated by strong cambering and dip-and-fault structure in the ironstone on the valley side to the south. Little time was available for collecting, but *Kallirhynchia sharpi* Muir-Wood and *Pholadomya lirata* (J. Sow.) were obtained from the Great Oolite Limestone and *Microthyridina lagenalis* (Schlotheim) from the Cornbrash, the latter form being indicative of Upper Cornbrash.

Monday, June 9th

FINEDON, CRANFORD, THRAPSTON AND ISLIP

The first halt was made at Finedon, where a walk southward along the foot of the mile-long old quarry face provided excellent exposures of the beds from the ironstone up to, and including the lower part of, the Great Oolite Limestone. *Burmirhynchia occidentalis* S. S. Buckman was collected from the Upper Estuarine Series. The ironstone itself is best seen at the entrances to a number of adits driven eastward from the old quarry floor to get the ore under deeper cover. In particular the irregular junction of the greyish-white ‘streaky’ kaolinitic oolite facies of the Upper Chamosite-Kaolinite Group with the underlying massive, even-bedded, Upper Siderite Mudstone is especially well seen. In one such adit roof-falls showed, below *Ostrea* beds of the Upper Estuarine Limestone, a 1-foot bed of Lower Estuarine silts with vertical rootlet markings passing down into the underlying shaly kaolinitic oolite. En route the party was met by Mr. J. N. Morley, Mine and Quarry Manager for the Wellingborough Iron Co. (Stanton Ironworks Ltd.), who, at the main entrance of the Thingdon Mine, gave an account of the methods of underground working and subsequently of the opencast working at the Wellingborough No. 5 Quarry next visited. Here the 10-14-foot ironstone face shows the usual succession of the eastern facies. Much of the ore is grey green carbonate stone and the overburden, which is unworkable chamositic and kaolinitic stone, Lower Estuarine silts and clays, and boulder clay, in all up to 30 feet thick, is removed by an electrically powered walking drag-line. This machine, by dumping the overburden evenly after first removing the top soil to the spoil heap, facilitates efficient restoration of worked-out ground. Much of the Upper Chamosite-Kaolinite Group occupies hollows cut in the beds below. It is largely fresh, green, unoxidised rock ; but included in it are considerable sporadic patches of sphaerosiderite. The latter appears to be a secondary development representing carbonation with some enrichment in iron, possibly a result of subsurface reactions in Lower Estuarine times (Hollingworth and Taylor, 1946, pp. 215 and 218).

Lunch was taken at Little Addington on the site of a small valley bulge which brings up ironstone to the surface at nearly the same altitude as the nearby Great Oolite Limestone.

After lunch the party visited the north-west corner of the Cranford South Ironstone Pit, where they were welcomed by Mr. W. J. Davenport on behalf of the Cranford Ironstone Co. (Staveley Coal and Iron Co. Ltd.). Collections made from the Great Oolite Limestone included *Epithyris oxonica* Arkell, *Kallirhynchia sharpi* Muir-Wood, *Stiphrothyris capillata* Arkell, '*Terebratula*' cf. *circumdata* E. E. Deslongchamps, *Anisocardia islipensis* (Lycett), *A. truncata* (Morris), *Cuspidaria ibbetsoni* (Morris), *Eocallista antiopa* (d'Orbigny), *Mactromya varicosa* (J. Sow.), *Modiolus imbricatus* (J. Sow.), *Pleuromya calceiformis* (Phillips), *Pseudolimea duplicata* (J. de C. Sow.), *Clypeus mulleri* Wright, *Nucleolites griesbachi* (Wright).

From Cranford South Pit the party proceeded to Bridle Limestone Pit, half-a-mile south-west of Islip. Here the Great Oolite Limestone was formerly worked for use in the neighbouring blast furnaces of the Islip Iron Co. The section exposed consisted of :—

	Ft.	Ins.
Cornbrash	5	6
Great Oolite Clay	14	0
Great Oolite Limestone up to	13	0

The Cornbrash at this pit has been described in detail by Douglas and Arkell (1932), who have shown that the upper 3 ft. 3 in. is Upper Cornbrash, the lower 2 ft. 3 in. Lower Cornbrash. Fossils collected by the party included *Cererithyris intermedia* (J. Sow.) and *Obovothyris obovata* (J. Sow.) from the Lower Cornbrash and *Microthyridina calloviensis* var. *globosa* Douglas and Arkell and *M. lagenalis* (Schlotheim) from the Upper Cornbrash as well as *Meleagrinella echinata* (W. Smith), *Pholadomya deltoidea* (J. Sow.) and *Pleuromya uniformis* (J. Sow.).

The Great Oolite Clay, as is usual in exposures which have not been freshly opened, was much slipped and obscured, but the characteristic blue-grey, green and purplish tints were locally visible.

The section in the Great Oolite Limestone showed the upper portions of this formation, the lower beds of which had been examined in Cranford South Pit. The lithological types present consisted of detrital shelly limestones, soft white argillaceous limestones and rubbly oyster-bearing limestones. In the lower beds current-bedding was locally well developed. Thin partings of fibrous gypsum and calcite were present throughout the succession.

Fossils collected included *Arcomytilus asper* (J. Sow.), *Isognomon* sp., *Ostrea* cf. *subrugulosa* Morris and Lycett (2 feet below top of limestone), *Protocardia* sp. and *Eocallista antiopa* (d'Orb.).

The last section visited during the day was at Marsh's Pit, 1 mile north-west of Islip. At this locality both the Northampton Sand Ironstone and the refractory silts and sands of the overlying Lower Estuarine Series have been worked. The main purpose of the visit was to inspect the fine examples of trough-fault gulls developed in the Lower Estuarine Series, into which Upper Estuarine beds and Great Oolite Limestone are let down. One gull was seen situated on the crest of a slight roll in the Northampton Sand with small scale dip-and-fault structure clearly discernible on either limb of the structure. The origin of these gulls has been discussed by Hollingworth, Taylor and Kellaway (1944).

The Northampton Sand in this section is heavily oxidised and belongs to the Main Oolitic Ironstone Group. Fossils collected by the party included *Gervillia* (*Cultriopsis*) *northamptonensis* Cox, *Pronoella ferruginea* Cox, *Tancredia donaciformis* Lycett and *Variamussium pumilum* (Lamarck).

On the return journey to Kettering a halt was made for tea at Wicksteed Park in the valley of the Ise Brook. Before leaving, the party was able to see something of the attractions of the park, the popularity of which was amply attested by the crowds present.

Monday, June 10th

STANION, CORBY AND COTTINGHAM

The final day of the meeting was sadly marred by rain, which started as the party was leaving Kettering and continued without interruption until its return. En-route for Corby a short halt was made at Geddington to see the fine Eleanor Cross in the centre of the village. The first section to be visited was at Cowthick Ironstone Pit, three-quarters of a mile east of Stanion. At the east end of the pit Upper Lias Clay, brought to the surface by a valley bulge, and overlain by the basal beds of the Northampton Sand, was exposed in a deep trench. Fossils collected from the Upper Lias Clay included *Grammatodon chapuisi* (Arkell), *Gresslya donaciformis* (Phillips), *Nuculana ovum* (J. de C. Sow.), *Oxytoma inequivalve* (J. Sow.), *Hildoceras bifrons* (Bruguiere), *Peronoceras* sp. and *Belemnites* sp. Dr. P. E. Kent pointed out that the presence of ammonites of the *fibulatum* group indicates the uppermost sub-zone of the Lias locally present. The thin band containing phosphatic nodules which occurs at the base of the Northampton Sand (Lower Siderite Mudstone-Limestone Group) was seen at this locality.

From the Northampton Sand the following were obtained: Rhynchonellid cf. *Rhynchonella cynocephala* Richard, and Terebratulids including cf. *Terebratula trilineata* Young and Bird and one similar to the new form from Hamson's clay pit south of Brixworth (p. 236).

Entering the main part of Cowthick Pit the party saw 5-6 feet of the Lower Lincolnshire Limestone (fine grained limestones and oolites) resting on a full succession of the Lower Estuarine Series (20 feet). A short distance westward the coarse shelly, current-bedded oolites of the Upper Lincolnshire Limestone appeared, with strongly discordant base cutting through Lower Lincolnshire Limestone and Lower Estuarine Series to rest locally on the Northampton Sand. Despite slipping and obscuring of the pit face, the irregularities of the base of the Upper Lincolnshire Limestone could be traced for some distance. At one point, where the Upper Lincolnshire Limestone rested on about 4 feet of Lower Lincolnshire Limestone, the bored surface of the latter at the plane of unconformity was clearly visible (see Taylor, 1946). Locally the limestone was overlain by as much as 25 feet of the Upper Estuarine Series, but these beds, at the top of the pit face, were not readily accessible.

Where the pit-face crosses the small valley which extends from the south-west corner of Harry's Wood southwards to Harper's Brook a good example of a bulge was seen. Upper Lias Clay was exposed in the core of a sharp carinate anticlinal fold which brought the Northampton Sand well up into the face of overburden above the normal level of the ironstone. On either limb of the fold the local succession of the Northampton Sand, comprising Lower Siderite Mudstone-Limestone Group and Main Oolitic Ironstone Group, was clearly seen.

After leaving Cowthick Pit the party halted for a short time at the end of Stanion Lane Pit, 1 mile south-east of Corby. Here Mr. J. R. Foster-Smith, who was accompanying the party on behalf of Messrs. Stewarts and Lloyds Ltd., gave a short talk on the Company's methods of working, which was much appreciated.

The next exposure to be visited was Longhills Pit, 1 mile east of Corby. At the western end of the old gullet leading into the pit some 8-10 feet of coarse shelly Upper Lincolnshire Limestone was seen resting on 1 ft. to 1 ft. 6 in. of massive fine-grained Lower Lincolnshire Limestone (see Taylor, 1946, Plate 21, B). This in its turn rested on the yellow-brown sands forming the uppermost beds of the Lower Estuarine Series. Eastwards along the gullet the Lower Lincolnshire Limestone disappeared and Upper Lincolnshire Limestone rested directly on Lower Estuarine Series. In the main part of the pit the channelling of the Upper Lincolnshire Limestone through Lower Estuarine Series on to Northampton Sand was clearly displayed (see Taylor, 1946, Plate 21, A).

At its maximum in this pit the Upper Lincolnshire Limestone attains a thickness of 40 feet. The oolitic freestones which yield the well-known Weldon building stone occur in the upper part of the section. The Roach bed, which is present approximately half-way up the succession, was not well exposed at the time of the visit. Fossils collected by the party included *Microrhynchia barnackensis* gen. and sp. nov. Muir-Wood MS., '*Terebratula*' (? *Rugithyris*) *weldonensis* sp. nov. Muir-Wood MS., *Mytilus principilaris* Whidborne, *Pholadomya fidicula* J. de C. Sow. and *Nerinea* sp.

Some members of the party proceeded along the pit to see the narrow vertical gulls in the limestone filled with boulder clay and limestone rubble (Plate 17, B). These are developed parallel to the valley on the southern side of which the pit has been opened.

After lunch a brief halt was made north-east of Corby at the end of Short Leys and Deene Pits, two of the deepest quarries working the ironstone. Time did not permit a descent being made into either, but the fine sections of Northampton Sand, Lower Estuarine Series and Lower Lincolnshire Limestone, overlain by a considerable thickness of Boulder Clay were seen from the top of the pits. The method of "top stripping" employed in these pits where the overburden is too thick to be removed in a single operation was also noticed.

The last exposure to be visited was a pit in Lincolnshire Limestone about quarter of a mile south of Cottingham. Here about 17 feet of Lower Lincolnshire Limestone was exposed, consisting of medium and fine-grained oolites, soft, sandy, fine-grained limestones and massive fine-grained shelly limestones. The lowest 4 feet of the section, believed to be about 12 feet above the base of the formation, showed a distinctive lithological type in which coarse ooliths are scattered through a much finer-grained oolitic ground mass. Fossils collected in the course of the visit included *Ceratomya bajociana* (d'Orb.), *Lucina bellona* d'Orb. and *Trigonia* sp.

From Cottingham the party returned to Kettering for tea at the George Hotel, where, after the President had moved the customary vote of thanks to the Directors, the meeting concluded.

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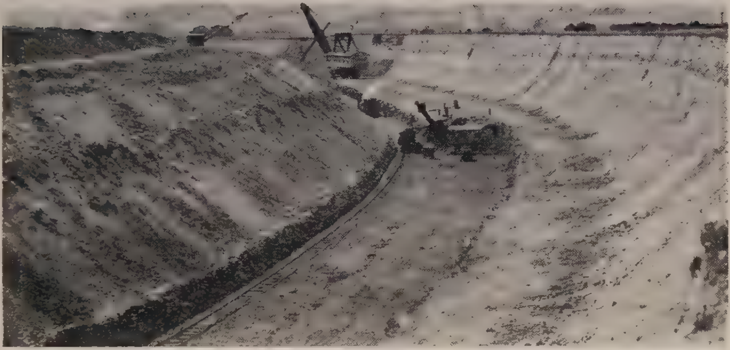
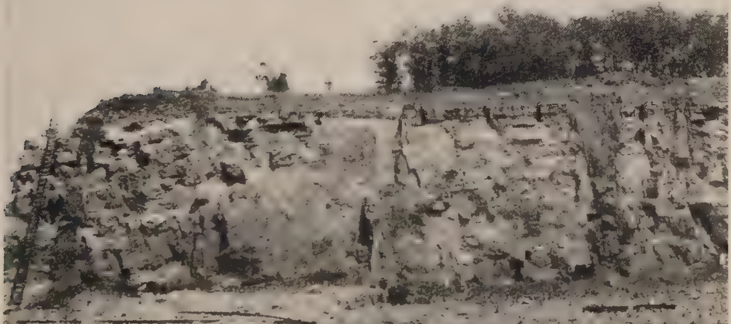


A.—NORTHAMPTON SAND IRONSTONE WORKINGS, LODGE PIT, NEAR IRCHESTER.



B.—NARROW BOULDER CLAY FILLED GULLS IN LINCOLNSHIRE LIMESTONE, LONGHILLS PIT, NEAR CORBY.

[*To face p.* 244.

EXPLANATION OF PLATE 17

(Numbers refer to photographs in the Geological Survey Collection)

A. Lodge Ironstone Pit, Irchester (A8193). Overburden is being removed by large quarry shovel and dumped on the worked out area (left), where it is roughly levelled by the drag-line. The smaller machine in the foreground is loading ore. The face of overburden, seen on the right, consists of some 55 feet of Great Oolite Limestone and Upper and Lower Estuarine Series.

B. Longhills Pit, near Corby (A8208). Narrow parallel-sided gulls in the Upper Lincolnshire Limestone are filled with boulder clay and limestone rubble.

EVIDENCE OF SUBMARINE EROSION IN THE LINCOLNSHIRE LIMESTONE OF NORTHAMPTONSHIRE

By J. H. TAYLOR, M.A., Ph.D., F.G.S.

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(*Read May 3rd, 1946*)

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SUMMARY

THE area described lies at the southern extremity of the lenticular Lincolnshire Limestone formation. Here an erosion interval separates Lower and Upper Lincolnshire Limestone, and the latter is largely preserved in discontinuous channels or elongated basins cut in the underlying beds. These channels have a generally consistent E.N.E.-W.S.W. trend and occupy a belt 2–3 miles wide running parallel to the present south-eastern limit of the main mass of the formation. The succession and lithology of the limestones and the nature of the junction between the lower and upper divisions are described.

The form of the channels indicates that they have their origin in submarine rather than subaerial erosion, and it is suggested that they are the result of tidal or current action. Their direction bears a general parallelism to the trend of movements that controlled the sedimentation and erosion of Inferior Oolite times in this area.

The economic bearing of the Lincolnshire Limestone channels on the working of ironstone and on water supply problems is briefly discussed.

I. INTRODUCTION

In the course of the six-inch mapping of the Northampton Ironstone Field, on which the Geological Survey has recently been engaged, opportunity has been afforded for a detailed study of the beds associated with the ironstone. Of these the Lincolnshire

Limestone is of special interest, both economically, since it forms a massive bed which has to be removed in order to work the ironstone by opencast methods, and scientifically, because of the problems in stratigraphy and sedimentation which it presents.

The Lincolnshire Limestone formation extends as a great lenticle from northern Northamptonshire through Rutland and Lincolnshire northwards into Yorkshire. The region dealt with in the present paper is situated at the southern extremity of this lens. It covers an area of about 150 square miles stretching from Kettering in the south to Harringworth in the north and from Desborough and Wilbarston in the west to Oundle in the east. In the 'sixties and 'seventies of last century this region was the scene of the classic work of Sharp (1870) and Judd (1875) who first conclusively showed that the Lincolnshire Limestone was of Inferior Oolite and not of Great Oolite age. Previously some brief petrological notes on the formation had been published by Morris (1853). More recently, a description of the Lincolnshire Limestone of Northamptonshire was included by Mr. L. Richardson and Dr. Kent (1938) in the report of a field meeting of the Geologists' Association at Kettering.

II. OUTLINE OF STRATIGRAPHY

The general succession of the solid formations present in the area is :—

		Feet.
	Cornbrash	up to 8
Great Oolite Series	Great Oolite Clay	10–20
	Great Oolite Limestone	15–25
	Upper Estuarine Series	34–45
Inferior Oolite Series	Upper Lincolnshire Limestone	up to 40
	Lower Lincolnshire Limestone (with Collyweston Slate locally at base)	,, 40
	Lower Estuarine Series	,, 25
	Northampton Sand (Ironstone)	,, 25
	Upper Lias Clay	170–190

Details of the lithology of these formations have been given elsewhere (Hollingworth and Taylor, 1946). In the present paper interest is centred on the beds between the Northampton Sand and the Upper Estuarine Series and in particular on the relations of Lower to Upper Lincolnshire Limestone and of both to the underlying and overlying beds (see later, p. 251.)

The chief variation from the standard succession outlined above is the absence of the Lincolnshire Limestone in the southern portion of the area. The main mass of the formation is confined to the north of a line running from Kettering in a general east-north-easterly direction to pass between Oundle and Glapthorn (see Plate 22). South of this line, in general, the two Estuarine Series come together. In the ironstone workings at Cranford and also near Denford, one-and-a-half miles south of Thrapston, they are separated locally by a few feet of fissile calcareous sandstone which may represent a development of the basal bed of the Lincolnshire Limestone.

III. SUCCESSION IN THE LINCOLNSHIRE LIMESTONE

Both Lower and Upper Lincolnshire Limestone are exposed in numerous workings for limestone and ironstone between Wilbarston and Rushton in the west and Weldon and Brigstock in the east. The generalized succession is given in Fig. 38. Locally, the basal beds of the lower division consist of a few feet of sandy fissile limestone representing a thin development of the Collyweston Slate. These beds are often largely decalcified and in Lower Brookfield Pit and Deene Pit north of Corby are represented by large isolated rounded masses of calcareous sandstone embedded in a matrix of yellow-brown sand. Where decalcification is complete it is often difficult to distinguish the resulting sands from the uppermost beds of the underlying Lower Estuarine Series.

Over much of the area, where the Collyweston beds are absent, the lowest representatives of the Lincolnshire Limestone are massive rather fine-grained limestones which in the hand specimen show little trace of oolitic structure. Frequently they contain turreted gastropods (*Nerinea*, *Nerinella*, *Ptygmatis*). In thin section (Plate 18, A) these rocks are seen to consist of organic debris together with many rounded or oval bodies in very turbid calcite. Only a relatively small number show oolitic structure. Many of them consist of a sand grain core round which a rim of turbid calcite has formed. In size they range from 0.10 up to 0.15 mm. across the longer diameter. Some of the organic fragments and ooliths have a centre of clear granular recrystallised calcite surrounded by a turbid rim. The groundmass consists of granular calcite, through which angular quartz grains are scattered in varying quantity.

These beds are succeeded by and interbedded with rather fine-grained oolitic limestones, many of which are highly siliceous. Frequently they contain a few large ooliths (0.3–0.5 mm. diameter) set in a groundmass of smaller ooliths (0.10–0.15 mm.) and organic debris. Increase in the percentage of large ooliths gives rise to a very characteristic rock in which the two generations of ooliths are clearly visible in the hand specimen. Large and small ooliths are scattered through a groundmass of clear recrystallised calcite (Plate 18, B). This rock type is particularly plentiful about the middle of the Lower Lincolnshire Limestone in the area under consideration. Upwards in the succession there is an increase in the number of large ooliths, and occasional bands contain ooliths ranging up to as much as 1 mm. in diameter. Rounded pellets of calcite mudstone and more rarely of oolitic limestone occur throughout the succession. In some cases both ooliths and pellets

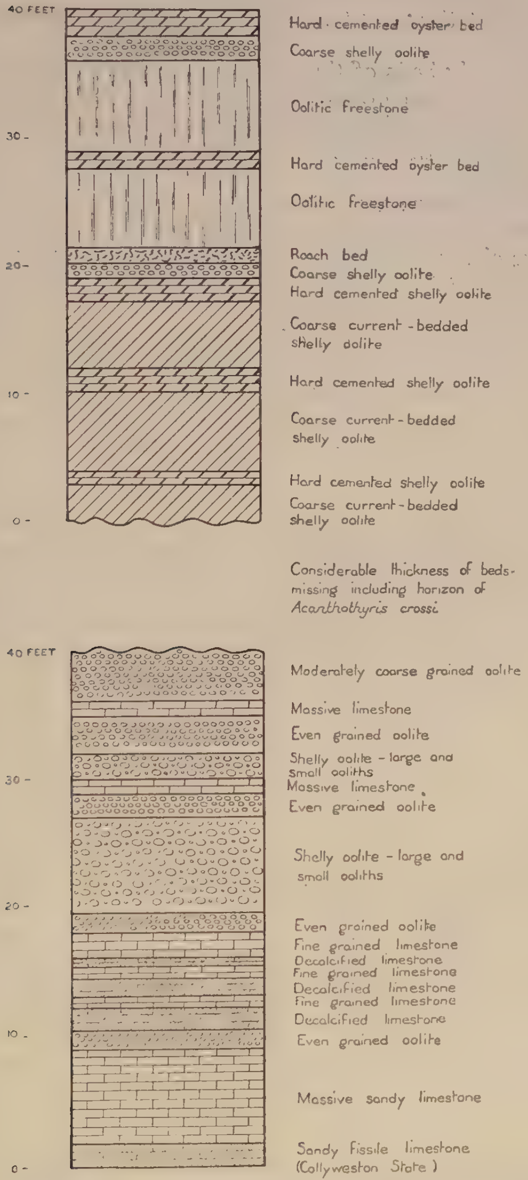

FIG. 38.—Generalised succession in Lincolnshire Limestone of northern Northamptonshire.

of calcite mudstone are marginally distorted by packing in a manner suggesting that they must have been relatively soft at the time of accumulation.

All the sandy beds of the Lower Lincolnshire Limestone show a tendency to become decalcified and to break down to a soft brown sand or sandstone. This decalcification is clearly shown in the bottom 20 feet of the limestone exposed in Prior's Hall Pit, 2½ miles N.E. of Corby.

Despite the large amount of shell debris present in the Lower Lincolnshire Limestone identifiable fossils are not abundant. Lamellibranchs are represented by *Anisocardia*, *Ceratomya*, *Lucina*, *Pholadodomya*, *Pinna* and *Trigonia*, corals by *Montlivaltia*, while certain beds are rich in serpulae.

The maximum thickness of the Lower Lincolnshire Limestone preserved anywhere in the district is about 40 feet, and it is even then overlain unconformably by the Upper Lincolnshire Limestone. The readily recognisable horizon of *Acanthothyris crossi* (Walker) which is widely developed further north is cut out by the unconformity.

The Upper Lincolnshire Limestone is represented by coarse-grained shelly oolites and oolitic freestones. Current bedding is widespread. The rocks consist of ooliths (averaging 0.5 mm. but occasionally up to 0.75 mm. in diameter), together with large shell and other organic debris, scattered rather sparingly through a groundmass of clear recrystallised calcite (Plate 19, A). The calcite of the ooliths is turbid : many of them consist merely of a marginal growth of radiating calcite round a core of calcite mud or a fossil fragment. Where an elongated shell fragment served as nucleus the resulting oolith is itself markedly unequidimensional. The large size of the organic fragments, the almost complete absence of sandy detritus and the high proportion of groundmass help to distinguish Upper from Lower Lincolnshire Limestone. Large rounded masses of turbid calcite up to 2 mm. across are common and presumably represent rolled fragments of calcite mudstone. There are, in addition, rather irregularly shaped bodies consisting of ooliths and small organic fragments in a turbid calcite matrix and surrounded by a thin rim of very fine-grained calcite mud. They range from quite a small size up to 15–20 mm. in diameter, and are a particularly characteristic feature of the Upper Lincolnshire Limestone in the old gullet leading to Longhills Pit, a mile east of Corby. Dr. Alan Wood has kindly examined these and suggests that they are of algal origin and represent loose material on the sea bottom cemented by " algal dust " (Wood 1941).

At various horizons in the Upper Lincolnshire Limestone lenticular bands of hard cemented shelly oolite, often containing abundant oysters (*Ostrea ampulla*, d'Archiac), occur. Some 15–

20 feet above the base there is locally a prominent *Mytilus*—or "Roach"—bed containing abundant casts of lamellibranchs and gastropods. Throughout the whole succession the little *Microrhynchia barnackensis*, Muir-Wood MS. and "*Terebratula*" (? *Rugithgris*) *weldonensis*, Muir-Wood MS., are present. In the Weldon area the oolitic freestones in the upper part of the formation have been extensively quarried as a building stone.

IV. RELATIONS OF THE LOWER AND UPPER LINCOLNSHIRE LIMESTONE

The relations of the Lower and Upper Lincolnshire Limestone to one another and to the beds above and below have been from time to time admirably exposed in the workings for ironstone in the neighbourhood of Corby. Fig. 39 shows a three-quarters of a mile long section of Cowthick Ironstone Pit, 2 miles E.S.E. of Corby. In this and Fig. 40 the top of the Northampton Sand Ironstone is taken as a datum. Throughout the section the Lower Estuarine beds where overlain by Lower Lincolnshire Limestone maintain their normal thickness of just over 20 feet. The Upper Lincolnshire Limestone rests with strong unconformity on the underlying beds and its base cuts down through Lower Lincolnshire Limestone and Lower Estuarine Series to rest in places on the top of the ironstone. The relation of the Upper Estuarine Series to the underlying beds is clearly seen. At both ends of the section it rests directly on Lower Lincolnshire Limestone, in the central part on Upper Lincolnshire Limestone. The unconformity between Upper and Lower Lincolnshire Limestone is also excellently exposed in Longhills Pit between Corby and Great Weldon (Fig. 40). Lower Lincolnshire Limestone is only preserved at the western end of the pit and in the old gullet leading down to it. For the greater part of the section the base of the Upper Lincolnshire Limestone channels down through various horizons of the Lower Estuarine Series or rests directly on the ironstone (Richardson and Kent, 1938). Plate 21, A illustrates the discordant base of the Upper Lincolnshire Limestone resting on Lower Estuarine beds and Northampton Sand Ironstone in this pit. Plate 21, B shows the coarse shelly beds of the Upper Lincolnshire Limestone separated from the Lower Estuarine Series by little more than a foot of the fine-grained basal bed of the Lower Lincolnshire Limestone.

Similar sections showing the relation of the Upper Lincolnshire Limestone to the underlying beds were at one time exposed in Stanion Lane Pit, a mile S.E. of Corby.

(a) Distribution and form of the channels

From the sections just described it is evident that the Upper Lincolnshire Limestone occurs in channels cut into the underlying beds. The distribution of these channels is clearly shown by an

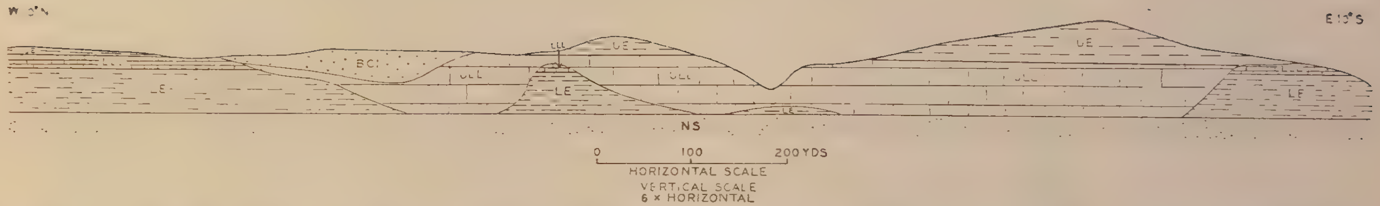

FIG. 39.—Section showing Lincolnshire Limestone channels, Cowthick Pit, two miles E.S.E. of Corby. Top of Northampton Sand taken as datum. B.Cl.=Boulder Clay, UE=Upper Estuarine Series, ULL=Upper Lincolnshire Limestone, LLL=Lower Lincolnshire Limestone, LE=Lower Estuarine Series, NS=Northampton Sand.

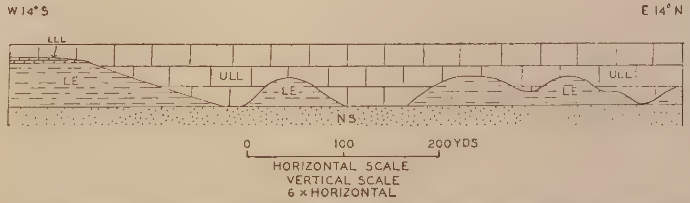

FIG. 40.—Section showing Lincolnshire Limestone channels, Longhills Pit, one mile east of Corby. Top of Northampton Sand taken as datum. ULL=Upper Lincolnshire Limestone, LLL=Lower Lincolnshire Limestone, LE=Lower Estuarine Series, NS=Northampton Sand.

isopachyte map of the Lower Estuarine Series (Plate 22). In the diagram evidence from pit sections has been combined with all available borehole data. Within the area covered by Plate 22 over 2,500 borings and trial holes for ironstone have been put down and these together with the records of a few wells and borings for water have been used in the construction of the diagram.[1]

In the north-west and south-east of the area the normal thickness of the Lower Estuarine beds is of the order of 20 feet except at certain points near the outcrop where it is less as a result of cambering. Over a central belt, however, the thickness is locally much reduced through channelling prior to deposition of the Upper Lincolnshire Limestone. In Plate 22 the black areas indicate regions where the Lower Estuarine formation has been completely removed and the limestone rests directly on Northampton Sand. The borehole evidence clearly shows that the channels are not continuous, but rather a series of elongated basins. These basins, which may be up to half a mile across and three miles long, are aligned with their axes in an E.N.E.-W.S.W. direction. Moreover, they are concentrated in a belt two to three miles wide extending from west of Pipewell eastwards to Little Oakley and thence in a general east-north-easterly direction towards Apethorpe and Woodnewton. As can be seen from Plate 22 the belt of channelling is approximately parallel to the present southern limit of the Lincolnshire Limestone.

Within the area under consideration the Upper Lincolnshire Limestone is largely confined to the main belt of channelling. Small patches occur locally outside this zone—e.g. at Wilbarston, between Weldon and Gretton and S.E. of Harringworth. There is little evidence, however, of any channelling of the Lower Estuarine beds north or south of the main belt save near Laxton and S.W. of Brigstock, where the thickness of the Lower Estuarine series is locally reduced to 5 feet. In neither case, however, is there adequate boring data to determine the cause or extent of this thinning.

Nowhere in the area covered by Plate 22 are thick developments of Upper and Lower Lincolnshire Limestone superimposed. The maximum thickness of each subdivision—about 40 feet—is very nearly the maximum thickness of Lincolnshire Limestone represented at any point (Hollingworth and Taylor, 1946, Plate 16, B).

The profiles of the channels are illustrated by serial sections (Fig. 41) along the lines indicated on Plate 22. In constructing these the top of the Northampton Sand has been taken as a datum. The sections are based on borehole records from which it is impossible to separate Lower and Upper Lincolnshire Limestone. Consequently the form of the channels within the Lincolnshire Limestone itself cannot be reproduced. In Fig. 41 the deeper parts of the channels, where they are cut into the Lower Estuarine

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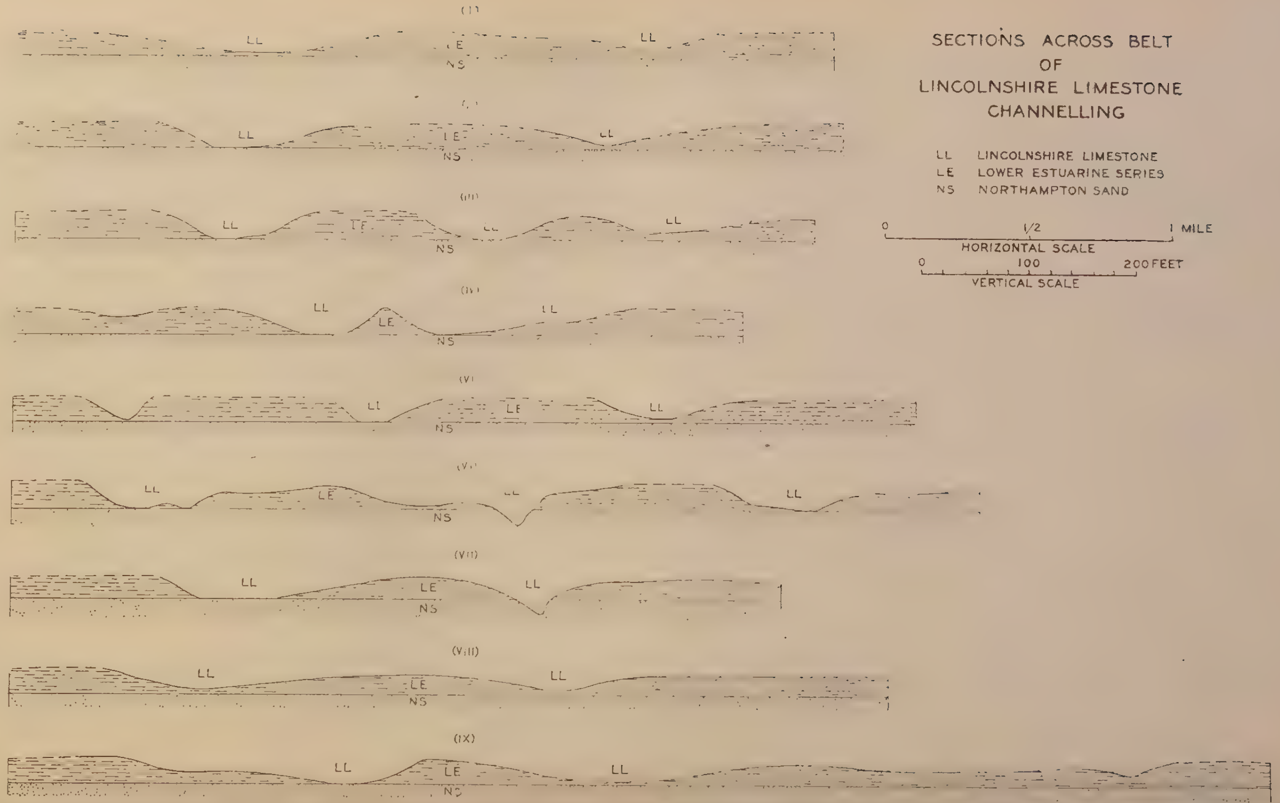
[1] Lower and Upper Lincolnshire Limestones are not in general separated in the boring records, and it is consequently impossible to produce an isopachyte map of either subdivision.



SECTIONS ACROSS BELT OF LINCOLNSHIRE LIMESTONE CHANNELLING

Series or Northampton Sand and which are accurate, are indicated by a full line. Where the Lower Estuarine Series attains its full thickness and the position of the base of the Upper Lincolnshire Limestone cannot be inferred the line indicating the top of the Lower Estuarine Series is broken. Thus it should be realised that the full depth of the channels may be considerably greater than that shown in the sections.

It will be seen that the maximum amount of channelling takes place in the central part of the belt, between the Oakleys and Weldon (sections (iii)-(vii)). Only in rare cases is there evidence of the channels having cut down below the top of the Northampton Sand (sections (vi) and (vii)). In the available exposures the top of this formation is generally seen to form the base of the channels (Figs. 39 and 40). However, from borehole data alone it is difficult to be certain that no erosion of the Northampton Sand has taken place and it is possible that channelling of the top foot or two of this bed may be more common than is suspected.

(b) Current bedding within the channels

Both large and small scale current bedding is widely developed in the Upper Lincolnshire Limestone. Wherever suitable exposures occur, e.g. near Pipewell, Little Oakley, Weldon, Stanion and Brigstock, the direction of dip of the large scale false bedding lies either between east and north-east or between west and south-west. The dominant directions of dip are thus approximately parallel to the trend of the channelled belt. Unfortunately there is a paucity of exposures of Upper Lincolnshire Limestone towards the north-eastern end of the area under consideration. Outside this area, however, near Wansford, on the eastern bank of the Nene, some 3½ miles N.E. of Woodnewton, Mr. R. F. Goossens has drawn the author's attention to large-scale current-bedding with a strong south-westerly dip in two exposures of the Upper Lincolnshire Limestone. This region is directly on the trend of the channelled belt. At Wall's Quarry, 1 mile S.S.E. of Wansford, where the current bedding is very striking, Upper Lincolnshire Limestone rests directly on the Lower Estuarine Series, while both to the north and to the south Lower Lincolnshire Limestone is present. It has already been suggested by Mr. L. Richardson (1939) that the Upper Lincolnshire Limestone is here occupying a channel cut in the earlier beds.

(c) The nature of the junction between Lower and Upper Lincolnshire Limestone

The junction between Lower and Upper Lincolnshire Limestone exposed in Longhills and Cowthick Pits frequently shows minor irregularities and undulations. The upper surface of the Lower Lincolnshire Limestone is, in some cases, cavernous and small portions project into the overlying Upper Lincolnshire Limestone. The small-scale bedding of the latter tends locally to follow the irregularities of the old erosion surface. In thin section (Plate 20, A and B) the contrast between the coarse Upper Lincolnshire Limestone and the fine-grained lower beds is particularly striking. It is evident from the sharpness of the junction that the Lower Lincolnshire Limestone was relatively compact before its erosion. On the other hand the fact that the top of the Northampton Sand so frequently forms the base of the channels and that these are only occasionally cut down into the Northampton Sand suggests that the Lower Lincolnshire Limestone was appreciably softer than the ironstone (but see p. 255).

The old erosion surface of the Lower Lincolnshire Limestone is commonly penetrated by borings and burrows which have become wholly or partly filled in by the coarser material of the overlying bed. Many of the borings appear to be the work of annelids, others of boring molluscs (*Lithophaga* sp.), which, in some cases, can still be found in position in their burrows. Plate 19, B shows a cross section of one of these burrows filled in with material from the Upper Lincolnshire Limestone. Locally large ooliths from the Upper Lincolnshire Limestone have penetrated 6-8 inches downwards into crevices in the underlying beds.

A conglomeratic appearance is, in places, imparted to the basal beds of the Upper Lincolnshire Limestone by the abundance of irregularly shaped fragments, apparently of fine-grained limestone. As already noted (page 250) these consist of Upper Lincolnshire Limestone material cemented together and surrounded by a thin skin of very fine-grained calcite and are probably of algal origin.

V. EVIDENCE OF TECTONIC MOVEMENTS IN INFERIOR OOLITE TIMES

There seems little possibility that the channelled belt has resulted from uplift and subaerial erosion of the area between Lower and Upper Lincolnshire Limestone times. Structure contours drawn on the top of the Northampton Sand show no trace of any anticlinal form along the belt of channelling. The belt is crossed obliquely in the west by the W.N.W.-E.S.E. Stoke Albany-Brigstock syncline and in the centre by the N.W.-S.E. downfold, of which the Rockingham syncline, the South Wood syncline and the Stanion-Aldwinkle trough all form part (see Hollingworth and Taylor, 1946). If uplift and erosion of the channelled belt in post-Lower Lincolnshire Limestone times were to be postulated it would be necessary also to invoke movements which restored the Northampton Sand to its original unwarped position prior to the folding which has since affected the area.

There is, however, some evidence that the Northampton Sand is thin under the belt of channelling. Owing to the fact that the majority of the borings in the area do not reach the top of the Upper Lias the data regarding thickness of the Northampton Sand is not conclusive. Fig. 42, however, shows three sections drawn where evidence is available and in each of these there is a distinct thinning of the Northampton Sand at some point beneath the channelled belt. In two of these cases, where the Upper Lincolnshire Limestone does not rest directly on Northampton Sand it is clear that this thinning can have no connection with erosion in Lincolnshire Limestone times. It may, however, be a consequence either of penecontemporaneous movement and local non-deposition of the ironstone in Northampton Sand times or alternatively of uplift and erosion of the Northampton Sand in pre-Lower Estuarine times. In the absence of any record of faunal or lithological horizons in

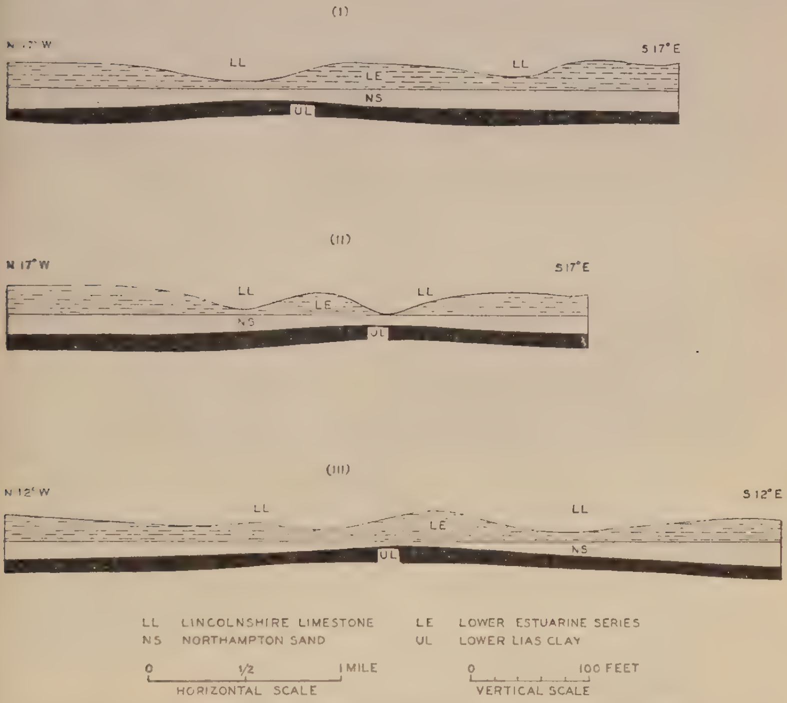


FIG. 42.—Sections across belt of Lincolnshire Limestone channelling to show thinning of Northampton Sand. Top of Northampton Sand taken as datum.

(i) Wilbarston to Rushton.
(ii) Bangrave Wood, one mile N.N.E. of Weldon to Farming Woods, one mile N.N.E. of Brigstock.
(iii) Blackmore Thick Farm, 2½ miles east of Deene to Benefield.

the details of the Northampton Sand, given in the borehole journals, it is impossible to decide which is the correct explanation. It seems possible, however, that the site of the channelled belt may have been an axis of slight instability in early Inferior Oolite times.

The direction of the channelled belt bears some relation to other formational and facies boundaries in the Inferior Oolite of Northamptonshire :—

(i) The southern limit of the main mass of the Lincolnshire Limestone, running from the neighbourhood of Maidwell (5½ miles S.W. of Desborough) through Kettering towards Oundle, has a general E.N.E.-W.S.W. trend. There is little trace of a littoral facies in the limestone as it approaches this line and the presence of what appear to be representatives of the earliest beds of the Lincolnshire Limestone near Cranford and Denford suggests that there was at least some sedimentation further south. Nevertheless, the present extent of the formation seems to have been determined by uplift along a general E.N.E.-W.S.W. line.

(ii) The white sand facies of the Lower Estuarine Series has been developed along a general N.E.-S.W. belt between Northampton and Oundle, lying mainly to the south of the Kettering-Oundle line.

(iii) The south-easterly limit of the Northampton Sand extends from the neighbourhood of Stoke Bruerne, near Towcester, north-eastwards towards Castle Ashby, south of Wellingborough, where it is interrupted by the N.-S. Doddington anticlinal axis (Hollingworth and Taylor, 1946). On the east side of this axis it follows a N.N.E.-S.S.W. line approximately parallel to the river Nene to pass east of Thrapston. There is some evidence that the Northampton Sand becomes more siliceous as it approaches this line and it is probably not far removed from the shore line of the time.

(iv) West of Kettering an E.N.E.-W.S.W. anticlinal axis extends from north of Draughton towards Rothwell. Over the crest of this anticline the Northampton Sand is locally thin and it may represent a line of pene-contemporaneous uplift.

It is thus significant that the channelled belt of the Lincolnshire Limestone bears a general parallelism to the trend of movements controlling the sedimentation and erosion of Inferior Oolite times.

VI. ORIGIN OF THE CHANNELS

From their discontinuous elongated basin-like form the channels in which the Upper Lincolnshire Limestone rests are clearly not a product of subaerial denudation. Local downcutting below the general level of sea or river bed is, however, a common feature of subaqueous erosion. H. S. Hallett (1881) has described the results of current scour in the deep water channel of the Hooghly river. Numerous large holes were known to have been formed within a period of 23 years, including one 52 feet deep and 9,000 feet long. The effect of tidal and current action in scouring out the sea bottom in the Bay of Fundy has been described by G. F. Matthew (1881). Matthew states, " A sudden elevation of the sea-bottom in the region of the Bay of Fundy to the extent of 250 feet would, therefore, now expose to view a chain of lakes varying from 50 to 150 feet deep, besides others of less extent and depth all due to tidal erosion." Although D. W. Johnson (1925) in general regards tidal and other currents (as opposed to wave action) as relatively subordinate factors in coastal erosion, he points out that they may " under favourable conditions independently excavate sea-bottoms or shores."

E. M. Kindle, in a study of the intertidal zone of the Wash (1928-9), has commented on the power of tidal currents in scouring out the discontinuous channels known as Boston Deeps and Lynn Deeps and, in particular, the deep trough known as The Well. Examination of Admiralty Charts of coastal areas shows numerous troughs and hollows in the sea floor, but in the absence of definite evidence regarding the nature of the bottom it is impossible to say how far these are due to non-deposition rather than to erosion.

It may reasonably be assumed that the channelled belt of the Lincolnshire Limestone was situated at no great distance from the shoreline of its time. Thus, while further north continuous sedimentation was laying down the complete succession of the Lincolnshire Limestone, in this area the earlier formed beds were locally scoured away and it is largely in the channels so formed that the higher beds have been preserved.

VII. ECONOMIC IMPORTANCE OF THE CHANNELLED BELT

The channelled belt is a factor of some importance in the working of the Northampton Sand Ironstone. Within the channels, in place of the normal soft silts, sands and clays of the Lower Estuarine Series, massive Upper Lincolnshire Limestone has to be stripped off as overburden in opencast workings. The use of explosives is generally necessary to shatter the stone before it can be removed by mechanical excavators. Moreover, within the belt there is the possibility that locally the top few feet of the ironstone may have been eroded in Lincolnshire Limestone times with a consequent reduction in the thickness of workable ore.

Both the Northampton Sand and Lincolnshire Limestone are water-bearing beds. Normally the presence of the impervious

Lower Estuarine Series prevents the percolation of water from the limestone into the ironstone. Where the Lower Estuarine beds are absent, however, and the Upper Lincolnshire Limestone rests directly on Northampton Sand, a free passage from overlying to underlying beds is permitted. This is liable to cause trouble with drainage in underground mining, since water, which outside the channelled belt would be retained in the Lincolnshire Limestone well above the level of the ironstone, may, within a channel, be discharged into the workings.

From the point of view of water supply, the superimposition of Lincolnshire Limestone and Northampton Sand may, on the other hand, prove an advantage. Good yields are to be expected from wells or boreholes sited in areas where the water normally present in the Northampton Sand has been augmented by the addition of water from the limestone. The satisfactory public supplies obtained at the pumping stations at Pipewell, Little Oakley and Stanion may be largely attributable to their situation with respect to Lincolnshire Limestone channels. Further supplies may be expected from sites similarly situated in or on the down dip side of channels.

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DISCUSSION

Mr. P. A. Sabine said that he was most interested in this description of the conditions of deposition of the Lincolnshire Limestone. In past years a great deal of work had been done upon marine sediments, mainly upon recent ones. It was therefore all the more interesting to hear described the conditions under which the Lincolnshire Limestone had been deposited and to have these conditions compared with similar ones which could be found in some parts of the world today.

The speaker had been fortunate in seeing these Jurassic rocks in the field with Dr. Taylor and felt that in the light of the evidence of the large number of sections which the author had described, his interpretation of the extensive borehole data was correct.

It would be interesting to know if evidence of lateral variation had been found in the Lincolnshire Limestone. Owing to the unusual nature and small area of the outcrop of the Upper Lincolnshire Limestone, the chances of finding variation from north-west to south-east were small. If, however, variation were present, then the speaker would like to know if any evidence had been forthcoming for an Upper Lincolnshire Limestone shoreline to the south-east of the channelled belt. The speaker also wished to ask whether any variation had been found in the Lower Lincolnshire Limestone and, if so, whether it could be correlated with the fairly well delineated south-eastern feather-edge of the formation.

Mr. T. Deans enquired whether there was any evidence of phosphatisation, such as is frequently associated with marine non-sequences, or other chemical change having taken place at the eroded surface of the limestone.

Mr. A. S. Kennard stated that some recent borings at Burnham-on-Crouch had revealed the presence there of an estuarine channel 130 feet deep. It was, from the abundance of *Corbicula fluminalis*, of Pleistocene age, and the whole series was of one age. Clement Reid had noted that at Happisburgh half a mile from the shore, he found a rocky bottom at a depth of 10 fathoms and a submarine cliff reaching to 15½ fathoms. Six weeks later, on a second survey, these features had disappeared and the depth was only 6½ fathoms, thus showing that deposition in a channel could be very quick (*Mem. Geol. Survey*, "The Pliocene Deposits of Britain," 1890, p. 173).

Mr. A. Wrigley also spoke.

The Author wishes to record his indebtedness to Professor S. E. Hollingworth for reading the paper, which he was unable to deliver personally, and to thank members for their comments and suggestions. As Mr. Sabine had pointed out, the chances of finding lateral variation across the relatively narrow belt of Upper Lincolnshire Limestone were slight. Actually, this subdivision was very constant in lithology, not only in the area under consideration, but also to the north-east and north-north-east in the neighbourhood of Wansford and Barnack. A greater range of rock types was to be found in the Lower Lincolnshire Limestone, but there was no evidence anywhere of a shore-line facies. The present south-eastern limit of the formation appeared to be an erosional line.

In reply to Mr. Dean's query, no evident traces of phosphatisation were associated with the junction between Lower and Upper Lincolnshire Limestone. Possibly strong current action had prevented the accumulation of phosphatic compounds within the channels. The general absence of ferruginisation at the surface of unconformity might be attributable to the same cause.

Mr. Kennard's reference to the deep channel containing Pleistocene fossils at Burnham-on-Crouch was most interesting. Both in this example and in the case of the irregularities on the sea bottom near Happisburgh, cited by Clement Reid, it was evident that sedimentation in submarine channels could be a relatively rapid process. Clement Reid had commented on the prevalence of submarine denudation in coastal areas at depths considerably greater than was possible in the open sea.

EXPLANATION OF PLATES 18 TO 22

(E. numbers refer to microscope slides and M. numbers to photographs in the Geological Survey collection)

PLATE 18

A.—Lower Lincolnshire Limestone, basal bed, Short Leys Pit, 1½ miles north-east of Corby (E. 21216, M. 2283). Small ooliths and rounded bodies of turbid calcite together with organic debris in calcite matrix. Ordinary light. X. 15.

B.—Lower Lincolnshire Limestone, approximately 15 feet above base, pit ¼ mile south of Cottingham (E. 21229, M. 2282). Large ooliths and rolled fragments of calcite mud in finer-grained oolitic matrix. Ordinary light. X. 15.

PLATE 19

A.—Upper Lincolnshire Limestone, basal bed, Longhills Pit, 1 mile east of Corby (E. 21120, M. 2281). Ooliths, rolled fragments of turbid calcite mud and oolitic concretions, together with coarse organic débris in clear recrystallised calcite matrix. Ordinary light. X. 15.

B.—Upper Lincolnshire Limestone filling burrow in Lower Lincolnshire Limestone, Longhills Pit, 1 mile east of Corby (E. 21121, M. 2280). Burrow in fine-grained oolite of Lower Lincolnshire Limestone is filled with coarse oolitic material of Upper Lincolnshire Limestone. Some secondary limonitisation has occurred. Ordinary light. X. 9.

PLATE 20

A–B.—Junction of Lower and Upper Lincolnshire Limestone, Longhills Pit, 1 mile east of Corby (A, E. 21118, M. 2278 : B, E. 21120 A, M. 2279). Coarse-grained Upper Lincolnshire Limestone resting on an irregular surface of fine-grained Lower Lincolnshire Limestone. Ordinary light. X. 9.

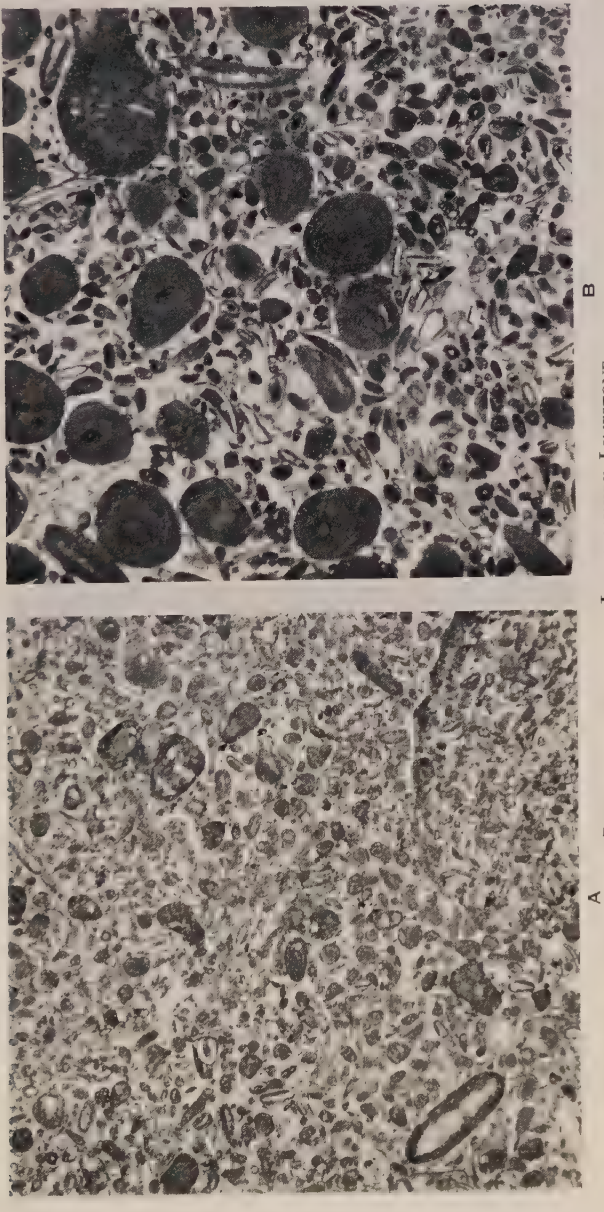
PLATE 21

FIG. 1. Upper Lincolnshire Limestone in channel, Longhills Pit, 1 mile east of Corby. Rails are on the bared top of the Northampton Sand, which has been shattered by blasting in the foreground. The top of the overlying Lower Estuarine Series (left) has also been bared and the discordant relation of the Upper Lincolnshire Limestone is clearly visible.

FIG. 2. Lower and Upper Lincolnshire Limestone on margin of channel, Longhills Pit, 1 mile east of Corby. Some 8–10 feet of coarse shelly Upper Lincolnshire Limestone rests on 1 foot to 1 foot 6 inches of massive fine-grained Lower Lincolnshire Limestone which in turn rests on the sands of the Lower Estuarine Series.

PLATE 22

Isopachyte map of Lower Estuarine Series of northern Northamptonshire, showing extent of channelled belt of Lincolnshire Limestone.



PHOTOMICROGRAPHS OF LINCOLNSHIRE LIMESTONE.

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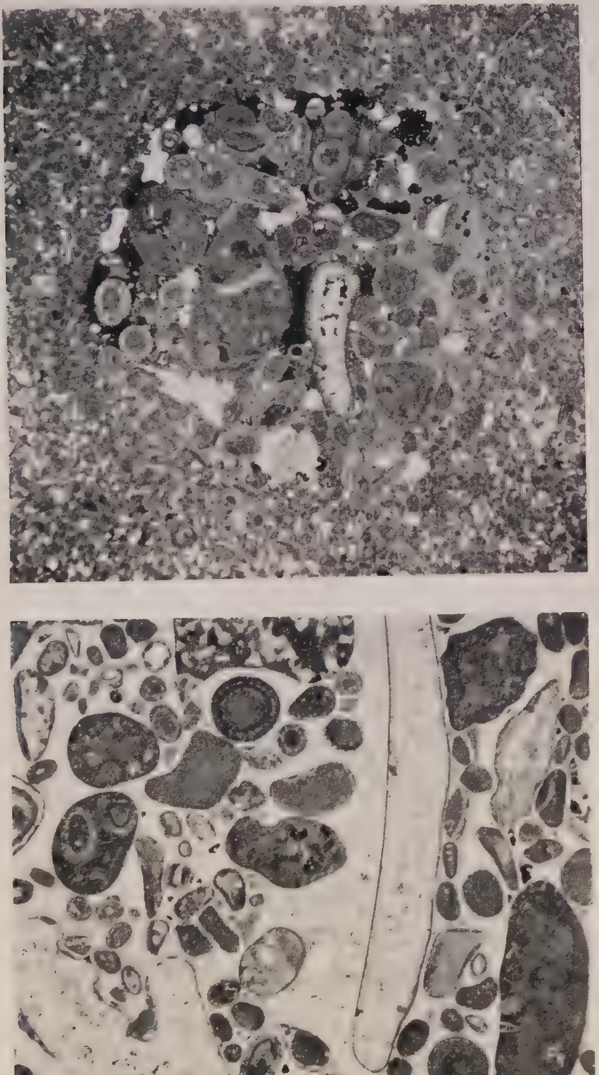

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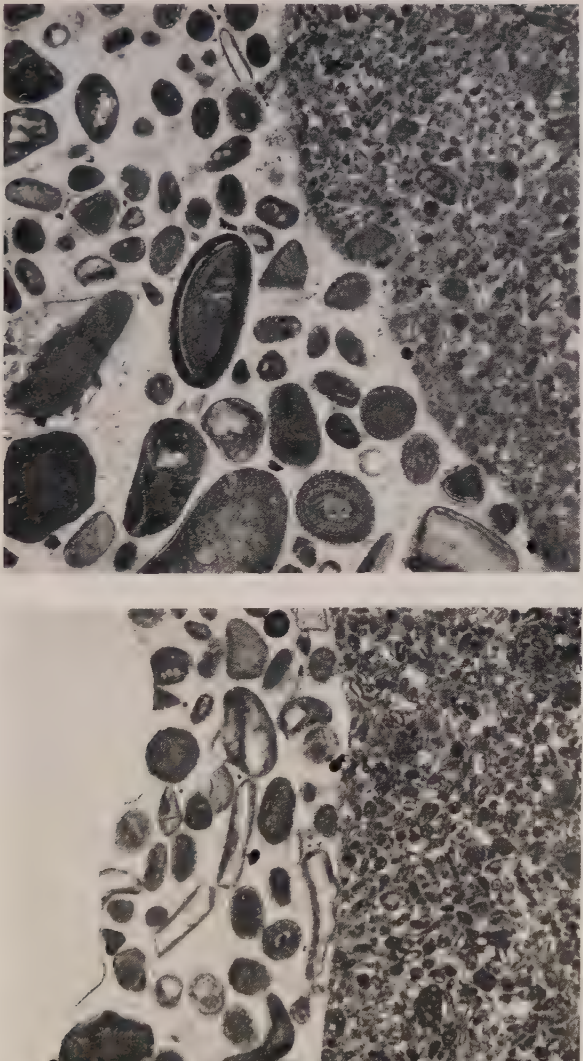

Photomicrographs of Lincolnshire Limestone.

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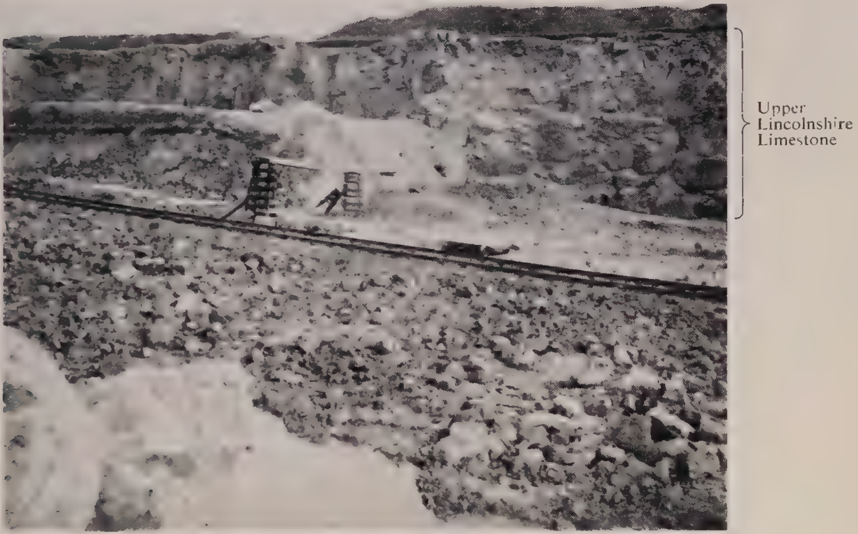
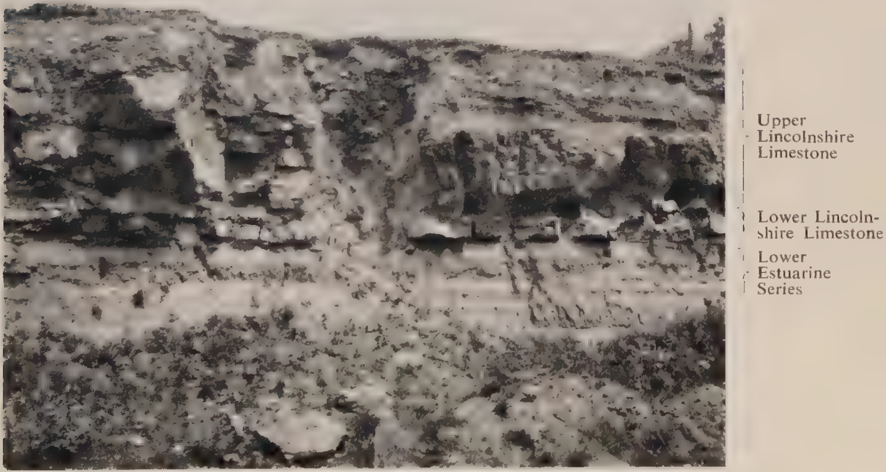


A.—UPPER LINCOLNSHIRE LIMESTONE, SHOWING UNCONFORMABLE BASE.



B.—LOWER AND UPPER LINCOLNSHIRE LIMESTONE.

LINCOLNSHIRE LIMESTONE IN CHANNELLED BELT, LONGHILLS PIT, NEAR CORBY.

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THE RELATIONSHIP OF SLATY CLEAVAGE AND KINDRED STRUCTURES TO TECTONICS

By GILBERT WILSON, Ph.D., M.Sc. (Wisconsin), F.G.S.

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I. INTRODUCTION

OVER the past 50 years American, and more recently certain European geologists, have been making valuable contributions to the solution of problems in structural geology by the aid of minor structures seen in folded rocks. Such phenomena as cleavage, foliation, drag folding, etc., can be readily observed in the field and should be used as a tool by every working geologist. In strongly folded or unfossiliferous rocks they have been utilised with remarkable results not only in pure scientific geology, but also in economic geology where both the geologist's reputation and large sums of money depend upon the correct elucidation of the structure. In this country the cleavage problem was enthusiastically tackled by the early workers, but after Harker's (1885–6)[1] communication to the British Association little serious attention, with few exceptions, seems to have been paid to the subject until recently. Even in the early 1930's we read that ' the genetics of cleavage are but little understood ' despite the fact that Leith's *Structural Geology* (1923) amplified by Swanson's (1927) paper on Stress and Strain give the field geologist enough material for at least an attractive working hypothesis. Many British geologists tend to consider cleavage as an unnatural hazard put there ' to make it a bit more difficult.' Because of this outlook we often hear the palaeostratigrapher's lament that the rocks were badly cleaved and fossils unidentifiable, in contradistinction to the structural geologist who speaks of ' well developed fracture cleavage ' and how ' it is quite easy to identify those beds which are overturned and those which are normal by the use of cleavage alone.' (A. Leith, 1931.)

This paper is an attempt to put forward some of the uses of as well as a summary of the development of the various types of rock-cleavage. In general it is confined to the study of those phenomena that occur in rocks which have not been highly metamorphosed, though the development of schistosity is discussed in the last section of this article. In some ways it may be considered an introduction to the more abstruse subject of *petrofabrics* or *structural petrology*, the understanding of which largely hinges on the general principles here outlined.

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[1] A list of works to which reference is made is given at the end of the paper.

In writing this paper I am indebted first and foremost to Professors C. K. Leith and W. J. Mead whose lectures some twenty years ago aroused my interest in structural geology. Since then the principles they taught—many of which are outlined here—have been of the greatest practical value in deciphering structures in severely folded areas of Pre-Cambrian and older Palaeozoic rocks. Much material has been gathered from the works of other geologists past and present to whom I am grateful. Recently published text-books by C. M. Nevin and E. S. Hills cover much of the ground discussed here. M. P. Billings' *Structural Geology* which only came into my hands after the paper was submitted for publication shows so much in common with what is here printed that I feel I owe him an apology rather than simple acknowledgment.[1]

To numerous students and colleagues I owe much for friendly discussion in the field and laboratory, particularly to Dr. R. M. Shackleton and Professor H. H. Read whose helpful criticisms and encouragement in preparing this paper have been invaluable.

II. SLATY CLEAVAGE

Although cleavage and related structures of secondary origin had long been recognised by the early geological workers, opinions regarding their formation and indeed their specific type were diverse. Fortunately much of the early history of the ' Cleavage Problem ' has been summarised by Harker (1885–6). This article is dominantly concerned with slaty cleavage—the cleavage which is so well developed that the rock has ' a capacity to part along parallel surfaces determined by the parallel arrangement of the longer axes of unequidimensional mineral particles and by the parallel arrangement of mineral cleavage in certain unit mineral particles.' (Leith, 1923, p. 113 ; Swanson, 1941, p. 1246.) Slaty cleavage, which is also referred to as *Flow cleavage* and grades into *Schistosity*, is distinguished by Harker, Leith and Swanson from *Fracture Cleavage*, strain-slip cleavage, etc., which are considered to be purely mechanical phenomena. The latter are formed by parallel closely spaced fracture-planes cutting the rock, and between individual pairs of planes there is no special tendency for the rock matter to split parallel to them. They grade into close-jointing as the fracture planes become more widely spaced.

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[1] The Geological Society's copy of Billings' book was received 27/3/46 · this paper was handed to the Editor of the *Proceedings* of the Geologists' Association on 1/2/46.

Harker (1885–6) describes how such geologists as Sedgwick, Phillips, Sharpe, and Darwin quickly recognised that cleavage was ' parallel to the main axes of elevation ' (p. 815), or as we would say now-a-days parallel to the tectonic trend or *b*-direction[1] of a folded belt ; and that cleavage cut across the bedding where the latter was folded. The parallelism of slaty cleavage to the axial planes of folds was first remarked on by Sorby (1853, 1856) though this relationship between cleavage and structure had already been figured by Sedgwick (1846, fig. 4, p. 114) in the Ireleth Slate Quarry. It is also to Sorby that credit is given for showing that ' all the main facts connected with slaty cleavage are explicable as the distortion of the mass of rock consequent upon lateral compression.' (Harker, 1885–6, p. 816.)

This relationship between cleavage and rock distortion or strain was investigated by numerous workers who by comparing the dimensions of similar fossils obtained from uncleaved and cleaved rocks were able to estimate the relative amounts and directions of shortening and extension that the cleaved rock had suffered, and how these compared with the orientations of the cleavage planes. The results obtained were confirmed by consideration of other types of deformed inclusions in cleaved rocks, such as the directions of extension and flattening in breccia fragments in Lake District slates, and the change in shape of green spots which were originally spherical in the slates of North Wales.

The conclusion reached was, to quote Sharpe's (1847) words, ' that rocks affected by slaty cleavage have suffered a compression of their mass in a direction everywhere perpendicular to the plane of cleavage, and an expansion in the direction of cleavage dip . . . . there was no proof that the rock had suffered change in the direction of strike of the cleavage-planes.' Equidimensional inclusions in the cleaved rocks were drawn out in a manner that agreed with these conclusions, and originally spherical spots in slates were deformed into triaxial ellipsoids with the longest axis parallel to, and the shortest axis normal to, the cleavage-planes. Recent striking examples have been described by Cloos and Hietanen (1941, pp. 83–4) in Maryland. Oolites and blebs in volcanic rocks have been deformed. The ratio between the longest and shortest axes of the oolites varies from 7 : 1 to 1.2 : 1. The volcanic blebs are described as being in extreme cases ' . . . paper-thin, up to one inch wide and a foot long, thus forming lenticular bodies whose longest axes are strictly parallel. . . . The lineation [elongation] is within the cleavage plane and thus is independent from bedding. . . . Its trend is roughly perpendicular to the axes of the uplift and the folds.'

---

[1] The use of co-ordinates in describing folds or tectonic movements is strongly advocated by workers in structural petrology (Sander, 1930 , Cloos, E., 1937 and 1946). *a* is the direction of movement or translation ; *b* is at right angles to *a*, and in a fold is the direction of pitch ; *c* is normal to *a* and *b*. The axial plane of a fold thus lies in the *ab*-plane of the system. A set of such co-ordinates are shown in Figs. 3 and 11. It should be noted that as the *a*-direction is normal to the pitch and lies in the axial plane. It is only vertical in the case of an upright horizontal fold.

It was upon this definite field evidence that the relationship of cleavage to deformation in terms of a *Strain Ellipsoid* was developed. (Harker, 1885–6, pp. 817, ff.) The theory is based on the conception of an imaginary sphere in the rock—one can picture it as a concretionary spot, a clay pellet, or a conglomerate pebble—the deformation of which is considered representative of the deformation of the rock as a whole.

The sphere, Fig. 43a, is first considered in a state of rest held in place by the weight of superincumbent rock and the retaining pressures of surrounding material. As tectonic forces begin to act on the area the sphere becomes deformed and its shape will change in a much greater degree than will its volume ; in fact we can assume for purposes of simplicity that there is no volume change.

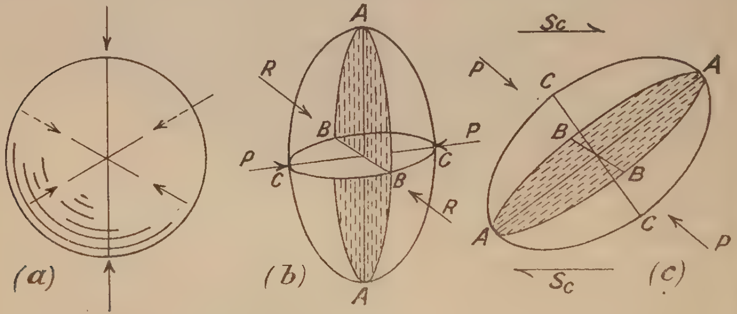

FIG. 43.—The deformation of a sphere (*a*) into a triaxial ellipsoid (*b*) by pressure parallel to *PP* ; the intermediate axis *BB* is held at constant length by retaining pressures *RR*. The *AB*-plane is normal to the greatest direction of shortening. In (c) the forces causing a similar deformation are a combination of pressure *PP* and a turning couple *SS*.

To begin with we shall consider the tectonic forces as acting as a simple squeeze, such as would be produced in a vice. The stress is simple and nonrotational. With this conception in mind we can picture the strata of the area being folded into upright symmetrical folds as illustrated by Sorby (1853) at Ilfracombe. The direction of relief is up and down, and the crustal shortening at right angles to the trends of the folds. The original sphere is now being compressed along one diameter *CC*, and in order that the volume should remain constant one might expect it to extend uniformly at right angles to *CC*. This would transform it into a flat ellipsoid of revolution or an oblate spheroid in which sections normal to *CC* would be circular.

The passive retaining pressure of the surrounding rock material has, however, to be taken into account. This latter (*RR*, Fig. 43b) acts as a restraining force preventing extension of the ellipse ' sideways ' parallel to the direction of the tectonic trend of the area (*b*). According to Sharpe (1847) this is parallel to the cleavage strike and is the direction ' in which the rock had suffered no change.' This leaves us with one diameter of the original sphere unaltered in length so that the third principal diameter must be extended. The sphere is thus distorted into a triaxial ellipsoid, Fig. 43b, in which the diameter

AA is *longer* than that of the original sphere.
BB is *equal* to that of the original sphere.
CC is *shorter* than that of the original sphere.

The plane *AC* is the one in which the deforming forces were acting. The diameter *BB* is at right angles to this plane, and is the direction of cleavage strike and tectonic trend (*b*) ; and the plane *AB*, which is normal to the *greatest shortening* (*CC*), is found from field observations—deformation of fossils, conglomerate and breccia fragments, spots in slates, etc. (Harker, 1885, p. 820, 821, 824 ; Leith, 1923, p. 124–5)—to be the one which coincides with the direction of slaty cleavage.

It is unfortunately rare that such a simple application of tectonic forces as the vice-like case discussed above occurs in nature. It is obvious from the very scheme of things that a uniformly directed pressure acting at right angles to a line of uniform resistance can only happen in exceptional circumstances. In consequence, even if we imagine the jaws of the simplest geosyncline closing, we find that though the pressure distribution along the strike in the horizontal sense may be more or less constant, that in the vertical will be far from uniform. However, it is a recognised fact in mechanics that a complex system of forces acting at a point, such as we might expect in this case, can be resolved into a single applied force and a ' turning couple.' We can, therefore, consider our sphere as being acted upon by a relatively simple system which consists of a dominant pressure *PP* from one direction combined with a rotary movement S_c S_c (Fig. 43c). In general these will act in the same plane—a plane more or less vertical and at right angles to the trends of our folds—the *AC*-plane. This is rather a case of putting the cart before the horse because the fold-trend (*b*) is in reality *the result* of the application of the combined stresses.

This complexity of the forces does not greatly complicate the structures with which we are concerned. The original sphere, instead of being just squeezed, suffers a combination of compression and rotation. It is again deformed into an ellipsoid, but with a different orientation as far as its actual position in space is concerned : it becomes inclined.

In this inclined ellipsoid the diameter *BB* is still unaltered and remains the direction of cleavage strike ; *AA* is still the direction of elongation with the plane *AB* the cleavage-plane. The axis *CC* is still the direction of greatest shortening, *but it is NOT the direction of greatest applied pressure.*

It is common, but fundamentally incorrect, usage to state that the axis *CC* is the direction of greatest pressure. Only if the pressure were applied as though by a vice would this be so. In an area of vertical cleavage it might be true. We are dealing here with rock-movement : shortening and extension—the results of the application of complex forces which themselves are compressional and torsional. Cause must not be assumed, without careful analysis, directly from effect.

The production of slaty cleavage in a rock, as outlined by Harker (1885) is considered to be dominantly the result of compression. He believed it to be a purely mechanical process by which mineral grains were rotated or flattened into the *AB*-plane. He is supported by Goguel (1945) who is of the opinion that schistosity is of mechanical origin and that it only develops at right angles to the direction of maximum compression.

The influence of chemical action in the development of slates was discussed by Harker (1885, p. 845 ff.) and despite Darwin's (1846) proposal ' that the same power which has impressed on the slate its fissile structure or cleavage has tended to modify its mineral character in parallel planes,' he was averse (p. 849) to ' a return to the purely crystalline theory of slaty cleavage, as advocated by Professor Sedgwick '—in his classic paper on the Structure of large Mineral Masses (Sedgwick, 1835). However, he did admit that ' many of the rocks which we call slates have experienced a development of new minerals (such as micas, chlorites and epidotes) concurrently with the production in them of the cleavage structure, and that there appears to be a passage from such rocks into mica-schist and foliated gneiss.' This outlook did not meet with universal acceptance. Van Hise (1894–5, p. 635) records that ' the innumerable parallel minute flakes of cleavable minerals in slate, especially mica and chlorite, which are almost universally present, are in no case detrital, so far as observed by me, but have developed *in situ* . . . As soon as a new mineral particle has developed it is subjected to flattening and rotation precisely as is an original mineral particle.' Reade and Holland (1901, p. 126) working on slates from the Lake District reached much the same conclusion : ' . . . that chemical action bringing about mineralogical change is an important factor in the production of slaty cleavage.' These views were later accepted by Harker (1932) who remarks that ' . . . in the process by which . . . a shale becomes a slate, . . . material [largely micaceous] is recrystallised in more distinct flakes . . . they set themselves, *as they grow*, in planes perpendicular to the maximum pressure.'

Similarly Swanson (1941), who concisely summarises the various hypotheses used to explain slaty cleavage, considers most favourably the ' growth of new minerals in such a way that their longest dimensions and cleavages lie in planes normal to the direction of greatest stress ' ; or as we would say, normal to the direction of maximum shortening, with which must be combined the effect of flattening (Fairbairn, 1935).

From the foregoing summary of past and more recent work we can reach the following general conclusions with regard to slaty cleavage :

(i) We are dealing with slaty cleavage which should not be confused with other types of cleavage.
(ii) Slaty cleavage is parallel to the axial planes of folds—the *ab*-plane of the system, Fig. 45 ; S_2 in Fig. 53.
(iii) It therefore cuts the bedding at various angles.
(iv) It is developed normal to the direction of greatest shortening of the particular rock mass in question.
(v) It is a chemical or recrystallisation phenomenon as well as a mechanical one, and can be represented by the *AB*-plane of the strain ellipsoid.
(vi) Slates may by further reconstitution grade into phyllites or schists.

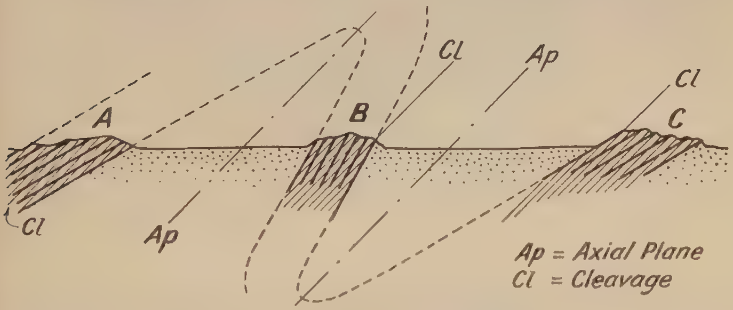

FIG. 44.—The relationship between slaty cleavage, bedding, and the axial planes of folds. The bedding at *B* is slightly overturned.

The question naturally arises : ' And so what ? How can this information be applied in the field ? ' The answer is best supplied by considering a theoretical example :

Fig. 44 illustrates a section across a slate series in which bedding and cleavage are recognisable. If cleavage alone could be observed we could only state that the tectonic trend was parallel to its strike and the inclination of the axial planes of the folds was parallel to the dip of the slaty cleavage. Even this, however, would be better than just mapping ' slates,' and letting it go at that. In exposures

A and C, however, we see that the bedding dips more gently than the inclination of the axial plane—and, therefore, more gently than the cleavage which is parallel to it. Hence we can say at once that the beds here are right way up : to use Bailey's excellent field term, they ' young ' to the left (1934, p. 469). On the overturned limb of the fold—exposure B—the beds are dipping in the same direction as, but at a steeper angle than, the axial planes. The bedding is, therefore, inclined more steeply than the slaty cleavage, an observation which tells that the beds are inverted—they ' young ' to the right. If we consider the exposures in pairs we find that going from A to B or from B to A the succession is descending in each case and an anticline must lie between them ; the beds between B and C, however, ' young ' inwards from the two exposures, the succession is ascending and the gap must contain a hidden syncline.

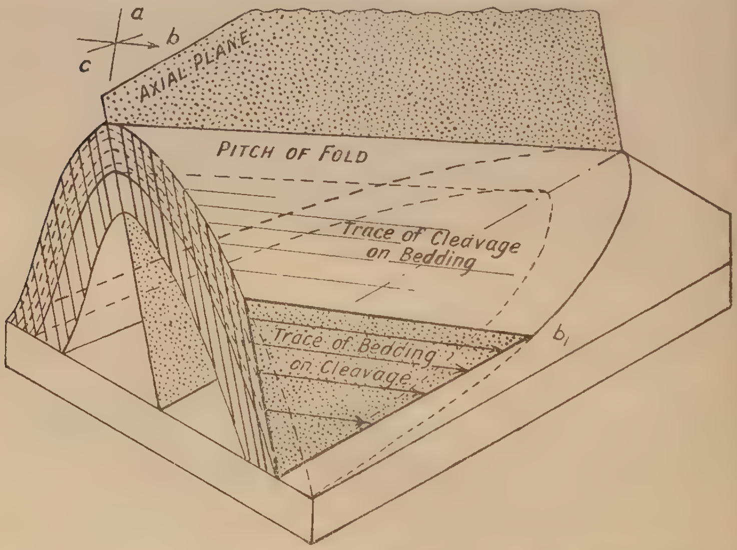

FIG. 45.—Showing the relationship between fold pitch and the intersection of bedding and slaty cleavage.

In plan the same holds true, and the direction of closure of a fold can be recognised by the relationship between the strikes of bedding and cleavage. This in turn gives the direction of pitch of the folds once it has been recognised whether they are anticlinal or synclinal.

It is worth noting that the angle between bedding and slaty cleavage varies with position on the fold. On the flanks of the folds the angular difference between the two is small, it may even be very small ; but near the axial line of the fold the intersection is at right angles. Thus in poorly exposed beds one can get an approximation as to whereabouts on a fold a particular outcrop may be situated. The same information can even be obtained from diamond drill cores provided both bedding and cleavage are recognisable.

Leith (1923, p. 183) has pointed out ' that the trace of the bedding on any cleavage surface gives approximately the pitch of the fold,' similarly the trace of the cleavage on the bedding yields the same result, Fig. 45.

He suggests the following demonstration to illustrate this phenomenon of pitch : ' If the student will fold a soft clay bed and section it in several places parallel to the axial plane, he will see that the intersections of the bedding with the planes of the several sections will give the direction of pitch, and usually the approximate degree or angle of pitch . . . . ' b_1 in Fig. 45.

The absolute direction of pitch naturally must lie in the axial planes of the folds which in turn give the tectonic trend of any particular area ; but by means of numerous observations by the method outlined above a general picture of large scale or tectonic pitch can be obtained without necessarily locating the axial planes themselves. This is the *B-direction* of the strain-ellipsoid of which the *AB*-plane declares the slaty cleavage plane or the fold axial plane, and it corresponds to the *b-direction* sought for in the modern methods of structural petrology or petrofabrics.

As will be shown later slaty cleavage differs from other types of cleavage, a fact which was recognised by Harker (1885), but which has led to marked divergence of views on cleavage formation. Leith (1905, p. 23) in his classical work on Rock Cleavage includes slaty cleavage in the term *Flow Cleavage* which he defines as ' the cleavage dependent on the parallel arrangement of the mineral constituents of the rock, an arrangement which developed during rock flowage.' It includes, according to this definition, schistose cleavage ; because with further recrystallisation a slate may reasonably grade into a phyllite or schist in which the foliation or cleavage direction is unaltered. This, however, is not always so and other factors may complicate the problem. The mechanism whereby slaty cleavage is developed is admirably summarised by Mead (1940), who points out that folding necessitates plastic deformation of some if not all the rock layers involved, and that this may be accomplished by intergranular rearrangement, such as the rotation of pre-existing flaky minerals, or by interatomic reorganisation, *i.e.*, the growth of new minerals under conditions of structural control. He argues that consolidation of shales, from which most slates are produced, takes a long time even geologically, hence they, being soft, may yield plastically during deformation by intergranular rearrangement without fracturing or cleaving. ' After the limit of intergranular plasticity is reached continued deformation demands interatomic plasticity. Folding proceeds with the development of flow (slaty) cleavage essentially parallel to the axial planes of the folds' (p. 1015). He thus accounts for the fact that many fine grained sediments have been severely folded without the development of any cleavage whatsoever. The relatively late development of slaty cleavage in a folded region as pointed out by Harker (1885–6, p. 852) is also explained by this mechanism of Mead's, and there is no need to appeal to some geological agency other than that responsible for the folding for its production.

Slaty cleavage is thus the response of the less resistant beds to the stresses imposed on the rock-system as a whole. The tectonic forces acting on a region which contains heterogeneous strata—competent and incompetent, that is to say, massive and easily deformed beds respectively—will throw them into a series of folds. These forces may be direct, like the jaws of a vice, or they may be rotational, in which case they can be resolved into one major force acting in a single direction combined with a couple. Their application on the region will result in folds having a certain tectonic trend and more or less asymmetry. Within the rocks themselves the massive (competent) beds—sandstones, limestones, lavas, etc.—will carry and resist the earth pressures, the plastic (incompetent) beds—shales, etc.—will yield passively until a certain limit is reached. This limit is controlled by such factors as increase in thickness due to crustal shortening, or recrystallisation of the chemically unstable fine grained rocks under conditions of directed pressure and increase of temperature due to generation of heat by internal friction. The forces which control the development of slaty cleavage are, therefore, the *resultants* of a complex system, but they act in the same direction as and are as equally responsible for the form of the folding as for the orientation of the cleavage. In this way the two phenomena folding and slaty cleavage have a common parentage, and because of this they have the family relationship outlined above.

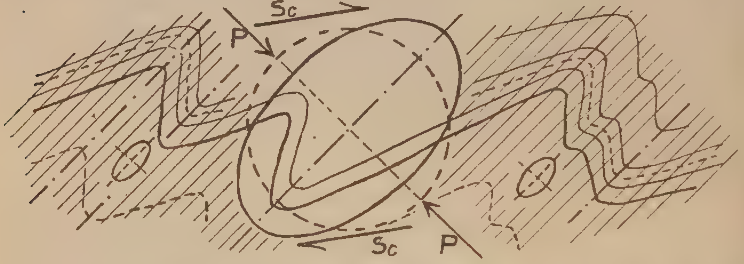

FIG. 46.—The general relationship between deformation folding, and slaty cleavage caused by pressures *PP* or the couple S_c S_c.

The foregoing paragraph is diagrammatically explained in Fig. 46. The deformation of the folded area may have been caused by pressures *PP or* by shears S_cS_c or a combination of the two ; in each case the crustal shortening is along the *CC*-axis of the ellipsoid normal to the axial planes of the folds and likewise normal to the *AB*-plane in which slaty cleavage develops. It is immaterial whether one considers the fold belt as a whole or a small section of one of the folds—the relationship is the same throughout.

In the discussion above I have dealt with the problem in its most simple form : there has only been one major fold episode, and fold axial planes have been parallel. Should the axial plane of the fold not be a flat surface, and Busk's (1929) work clearly demonstrates that it need not be, then the cleavage will curve with it. Thus one can visualise a fold of which the limbs are of undulating dip : to fit such a structure the axial plane itself must be warped, and similarly the direction of slaty cleavage will be expected to undulate in sympathy.

Should there have been repetition of folding after the original formation of the cleavage, then the latter would naturally be involved and contorted and considerable complications might ensue. In this way slaty cleavage can be a valuable guide to the age of tectonic episodes. If it shows marked divergences from what might normally be expected, then those divergences must be explained : the cleavage acts as a geological safeguard or indicator to the field geologist. In cases where the axial planes of a fold system are not parallel, the slaty cleavage will also tend to show lack of parallelism and will approach its normal relationship to individual folds only when well within those folds. Between divergent folds the cleavage will tend to swing, forming as it were a compromise between changing conditions.

III. ROCK FRACTURE AND FRACTURE CLEAVAGE

In the previous section I discussed the development of slaty or flow cleavage in a folded rock system and considered that it was the result of a chemical or recrystallisation process, combined with a flattening of mineral particles. Even among the earlier workers there were views held that this flowage process did not account for all the observed facts ; probably this was because it was not appreciated that all cleavage was not slaty.

Harker (1885, p. 828) has a section on the subject of ' Slaty Cleavage in Rocks of various Lithological Characters ' and illustrates it with three figures which show abrupt angular deflection and curving of the cleavage as it passes from fine grained rock through grit-bands, as shown here in Fig. 49d. This was noticed by Sorby (1853), who considered that the grit owing to its nature would be less compressed than the slate ; hence the cleavage being perpendicular to the compression would therefore be less inclined to the bedding of the former than it is in the slate, an argument which Harker accepted, but which is obviously fallacious. Phillips' (1843) suggestion that there is some connection between the actual process of folding and the cleavage direction in the gritty band is dismissed. As we shall see there is strong argument in support of Phillips' contention.

The first serious analysis of rock fracture considered from a mathematical-mechanical point of view was presented in 1893 and 1896 by Becker. In both papers his discussion of the problem is purely mechanical. The effect of Rieke's principle, whereby crystals tend to grow normal to the direction of compression, in the recrystallisation of slates, is not given consideration, and the idea that slaty cleavage be ascribed 'to the flattening of particles at right angles to the line of pressure and the rotation of mica scales towards the same position' is strongly debated.

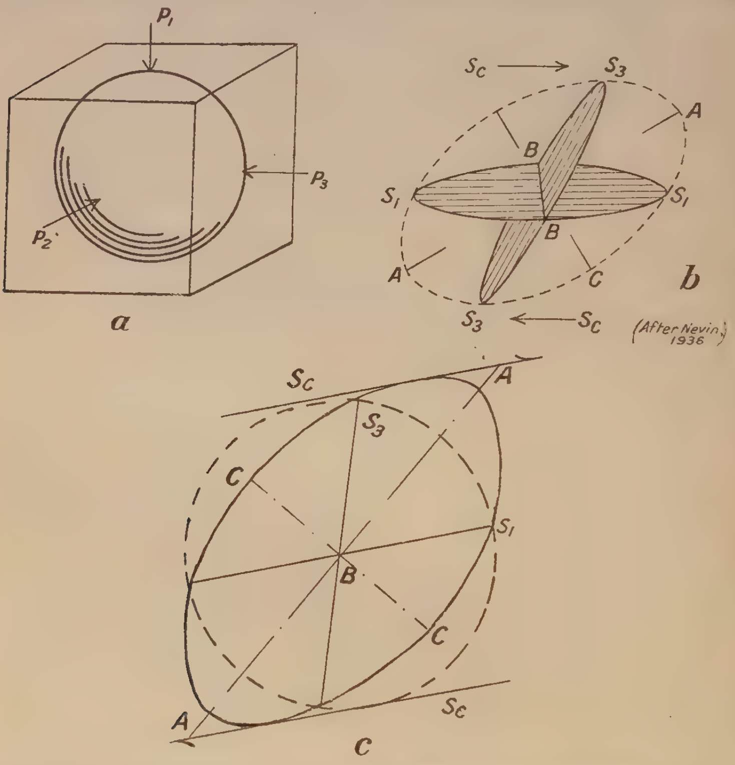

FIG. 47.—The development of two planes of maximum shearing strain (or planes of no distortion) S_1 S_3 in a triaxial ellipsoid produced from a sphere (a) by a couple S_c S_c.

Becker approaches the problem of rock fracture or rupture through the medium of the strain ellipsoid. He points out that when a sphere, Fig. 47a, is deformed into a triaxial ellipsoid of equal volume, Fig. 47b, and 47c, whether it be by pressure (mathematically 'pure shear'), or by means of a couple, S_cS_c (mathematically 'scission') there will be two circular cross-sections S_1 S_3 of the ellipsoid which will have diameters the same length as that of the intermediate or *B*-axis which represents the direction in which the rock has 'suffered no change.' Hence these two circular cross-sections will have the same diameters as had the original sphere. Over these two circular cross-sections, therefore, the material has not suffered either shortening or lengthening, neither compression nor extension: *they represent at any particular instant during the deformation of the sphere planes of no distortion.* It is along these two planes that the *maximum shearing strains* act when deformation is taking place. As the ellipsoid is slowly deformed the relative position of these circular sections changes. They close together and the angle between them becomes more and more acute. This means that the directions of application of maximum shear are changing correspondingly, and it is along the positions in which they happen to be when the rock is so distorted that it fails by shear, that theoretically the lines of break will form. Elsewhere in the ellipsoid the material is either being drawn out in the direction of the A-axis or is being compressed parallel to the *C*-axis. Admittedly the rock may fail under tension, in which case cracks will develop normal to the *A*-axis, *i.e.*, parallel to the *BC*-plane, Figs. 51 and 52a, and Pl. 23. Usually, however, the rock fails by shear along closely spaced cleavage planes sub-parallel to one of the two circular cross-sections of the ellipsoid. This failure is a slipping movement and that it occurred was originally suggested by Phillips (1843), and later by Laugel (1855), when the former proposed that cleavage was the result of 'a creeping movement among the particles of rock, the effect of which was to roll them forward.'

It has been argued (Griggs, 1935) that the strain ellipsoid concept should not be applied to material, such as we meet in structural geology, that has been deformed beyond its elastic limit. However 'experience with the intimate spatial and chronological relations of fracture and flow in rocks has led many field geologists to an affirmative view (Leith, A., 1937) . . . it has been found that empirical use can be made of the ellipsoid conception of strain in interpreting many rock structures. Recent work in structural petrology supports this view . . .' (Fairbairn, 1942.)[1]

The field application of the principles summarised above are based on the fact that when beds are folded by forces acting more or less tangentially to the earth's surface there is a strong tendency for upper beds to ride up over lower ones towards the apices of anticlines and away from the troughs of synclines. This can easily be illustrated by folding strips of felt or cardboard and noting relative slip between adjacent strips. De la Bêche (1853, p. 648) commenting on the effect of this phenomenon as seen at Waterford Harbour found '. . . well shown . . . the marks of friction produced upon adjustment of such consolidated beds as could move upon or against each other, the striation being often beautifully marked.' In the Jura, this slip has been so intense that the bedding planes are slickensided, and 'at many places both sides of the strong, thick layers of Jurassic limestone are polished as smoothly as if glaciated. They reflect the sun like an imperfect mirror.' (van Hise, 1896, p. 600.) Grooved slickensides on bedding have been noted in the Austwick Grits and Flags where they have been steeply folded in Crummockdale, and in the entrance to the present-day Arcow Wood Quarry, near Horton-in-Ribblesdale, West Yorkshire.[1] Similar structures are also described by Lewis (1946).

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[1] A general discussion of stress and strain hypotheses in rock deformation and fracture is given in Chapter VI of Fairbairn's valuable work on 'Structural Petrology' (1942)

The result of this upward slip between adjacent beds is to produce in each bed a shearing couple which acts on its upper and lower surface. On the top of any individual bed the shearing force is directed upward towards the anticlinal crest, and on the bottom it is downward towards the synclinal trough. The couple as a whole is controlled by the frictional drag between beds while they are undergoing folding. Hence the greater the depth of burial the greater the effect of the drag.

Massive or competent beds, such as sandstones, lavas, etc., will probably be able to resist this shearing force to a large degree, but incompetent material, particularly if it lies between competent beds, becomes deformed. It is drawn out, and if recrystallisation does not take place, will eventually reach the breaking limit and will fracture. Becker has shown how this fracture along shear planes will occur, and his theoretical results are borne out in nature.

In an introductory discussion on rock cleavage, such as this, it is legitimate to consider that the *B*-axis remains unchanged in length, and hence that the circular sections of the ellipsoid have the same diameters as that of the original sphere. 'In the case of rotational strain, produced by a shearing couple . . . . neutrality of the intermediate axis is to be expected.' (Griggs, 1935, p. 133.) We are, however, as Griggs points out, dealing with a special case when the ellipsoid and its relationship to the initial sphere are considered. Changes in the length of the *B*-axis are possible, and not unnaturally they lead to complications. But as far as the present discussion goes the *field evidence* supports the assumption that the *B*-axis remains constant. (Sharp, 1847 ; Leith, 1923.)

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[1] This phenomenon can be used for the determination of fold pitch : the direction of slip will be towards the axis of the fold. If the crest of the fold is horizontal the slickensides will be vertical ; if the fold is pitching then the slickensides will deviate from the dip direction of the beds by an amount similar to the pitch of the fold (Nevin, 1936, p. 45 ; and Nieuwenkamp, 1928). They will be lying in the *AC*-plane of the strain ellipsoid, the *ac*-plane of the fold co-ordinates, and will be normal to *b*.

Now we *know* the direction in which the couple S_cS_c is acting : it is upward towards the anticlinal crest and roughly parallel to the bedding on which in turn we *know* slipping occurs. Therefore, one of our planes of maximum shear S_1 (Fig. 47) must be parallel to it. The other plane S_3 is at an angle to S_1 and, therefore, to the bedding, and is inclined in the direction in which the couple is acting. The line of intersection of the two shear planes is, of course, the *B*-axis of the ellipsoid, and is at right angles to the plane in which the couple is acting. The angle between S_1 and S_3, or between the bedding and cleavage, depends upon the amount of deformation that the rock has suffered before fracturing. A poorly-resistant rock may be distorted to a considerable amount, in which case the two directions of shear (bedding and cleavage) will only differ by a small angle. A tougher rock may be able to resist deformation and be but little strained before it eventually fails ; in this latter case the ellipsoid would be ' stumpy ' and the two shear directions nearly at 90° to each other. Hence the cleavage dip in adjacent beds may differ considerably depending as it does on the lithological character of the strata. Continuation of folding after the initial fracture has been formed will cause slipping between individual cleavage units which will in turn be rotated to a more acute angle with the bedding. This results in the apparent strain shown by the relative shear directions being much greater than it actually was at the time rupture occurred. This slipping also leads to mechanical thinning of the bed on the fold-flanks. (Lovering, 1928 ; Becker, 1893.)[1]

Cleavage of this type—mechanical fracture or '*fracture cleavage*'—is not constant in orientation over the whole field. This orientation depends upon the nature of the rock, the frictional drag between adjacent beds, the steepness of the fold-flanks and the direction of any external directed pressures which may be acting on the system as a whole. These form a complex series of unknowns, and the orientations of the shear planes parallel to which fracture cleavage may develop cannot be foretold. One fact, however, will stand out : *the angular relationship between fracture cleavage and bedding will indicate the direction in which the beds have slipped, and the slipping is always upwards towards the anticlines.* This is illustrated in Fig. 48 and we see again here—as we saw in the case of slaty cleavage—that where the dip of the cleavage is steeper than that of the bedding the beds are right way up, where the dip of the cleavage is in the same direction as, but less steep than the bedding, then the beds are inverted. Fracture cleavage is *not* parallel to the axial planes of the folds, but, as in the diagram, it forms a roughly symmetrical fan-like structure about individual axial-planes.

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[1] Lovering's alternative theory on the formation of fracture cleavage is discussed later on p. 289.

A strong directed pressure acting on the rocks which are being folded will naturally affect the cleavage orientation. The material will then be subjected not only to the shearing action of the couple, but also to compression more or less oblique to the folded bedding. This will accentuate the drawing out of the ellipsoid and thus will modify the angle between the cleavage and bedding, making it more acute : the fracture cleavage-plane will closely approach that of slaty cleavage. This will not affect the structural value of the cleavage to bedding relationship.

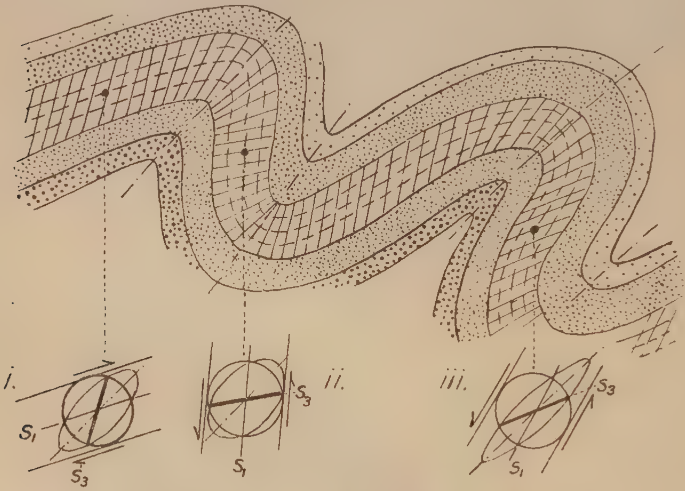

FIG. 48.—Showing the orientation of fracture cleavage relative to bedding in (i) where beds are right way up ; (ii) vertical beds ; (iii) inverted beds. S_1, Bedding plane slip ; S_2, Fracture cleavage.

The line of intersection between fracture cleavage and bedding, or the trace of one on the other (b_2 in Fig. 53), can be used in the same way to determine the direction of pitch of a fold or the *b*-direction as can slaty cleavage, but the direction so obtained is not as accurate as in the case of the latter.

Because fracture cleavage is dominantly due to the effect of internal shear on a bed which is being folded it reflects the intensity of deformation in that particular bed. A homogeneous bed which was equally responsive to the stress throughout its thickness will break along closely spaced parallel straight fractures, Fig. 49a. If there were easy slipping between one surface of the bed and the next above or below the distortion where that easy slip occurred would not be as great as that near the other surface, hence the cleavage would be less acute to the bedding where slip had taken place than it would be where the frictional drag was greater, Fig. 49b. (See also Cope, 1946, fig. 17, p. 154.) The curved cleavage can thus assume a false current-bedding appearance which in metamorphised rocks might be exceedingly deceptive. Where the deformation is greater at the top and bottom of the bed than it is in the centre the cleavage is sigmoidally curved (Fig. 49c.) This may also be caused by '*forced deformation*' of an originally straight cleavage which has been dragged over by continued movement of the beds after it had been formed. (See also McKenny Hughes in Lyell, 1885, p. 531.) Here the cleavage at the top and bottom approaches slaty cleavage in its orientation : the strain-ellipsoid must be exceedingly drawn out. In the case of graded bedding the coarse bottom material naturally is more resistant than the finer grained upper part. Consequently the shear planes at the base are less acute to the bedding than they are where the material is more easily deformed. The cleavage then becomes curved (Fig. 49d) after the style illustrated by Harker (1885, p. 828, see also Tanton, 1930, p. 75).

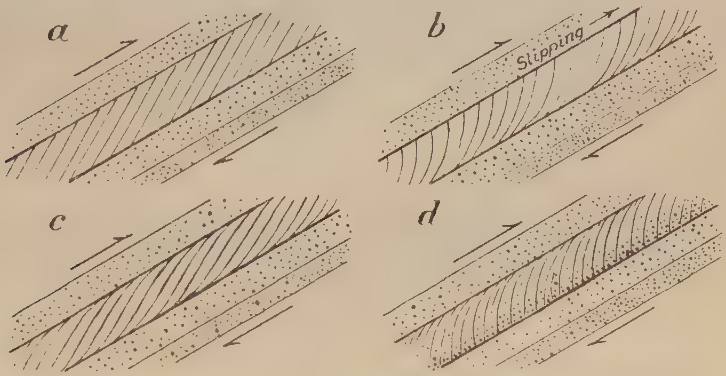

Fig. 49.—Types of Fracture Cleavage :—
- (*a*) Straight parallel fractures.
- (b) Curved fractures where deformation has been greater at the bottom of the bed because of slipping at the top.
- (c) Sigmoidally curved cleavage planes.
- (d) Curved cleavage in graded bed.

Fracture cleavage has been referred to in various terms in the past : false-cleavage, close joint cleavage, strain-slip cleavage, etc. Its appearance in the field varies from a very finely fissile structure in which the rock parts along closely spaced individual planes, to a close joint system in which the rock will break away in more or less parallel sided blocks. The spacing of the fracture planes depends largely upon the character of the rock. Softer beds usually show very close spacing of the cleavage planes so much so that the result may be indistinguishable from slaty cleavage in extreme cases. In more massive grits and limestones the cleavage may be more in the nature of a closed spaced jointing. In each case the material between the fractures is normal compacted sedimentary rock in which recrystallisation due to dynamo-metamorphism is not noticeable.

IV. COMBINATION OF SLATY AND FRACTURE CLEAVAGE

The two foregoing sections dealt with the development of slaty cleavage and fracture cleavage as entirely separate phenomena. In a sense they are: the former is largely due to recrystallisation and flattening of pre-existing platy minerals: the latter is purely mechanical; but which will be formed depends upon the conditions in the individual bed that is undergoing deformation. A rock system which is being folded is subject to external forces which may be direct pressure (*PP*), rotational stresses (S_cS_c) or a combination of the two, Fig. 50. Within the fold-belt the stresses will be carried mainly by the stronger beds, the folding of which controls the general structure of the area. The warping of these beds produces subsidiary stresses (*ss*) within the rocks themselves: stresses which are caused by the slipping of beds over each other and so are dominantly in the nature of local rotational shears which may act in the same general sense as, or against, the external stress couple. The condition can almost be described as 'wheels within wheels.'

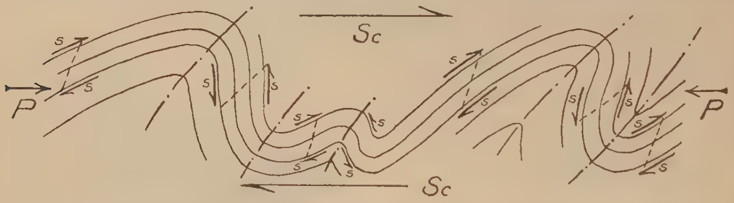

FIG. 50.—Subsidiary shearing stresses (*ss*) developed in a folded belt.

The cleavage development thus depends upon the balance between internal and external stresses acting on each particular horizon, as well as on the lithological character of the horizon. Some beds may deform plastically throughout the folding movements only to recrystallise as slates under the influence of the tectonic stresses when movement has ceased. Some may resist deformation and show little or no sign of recrystallisation or fracture; and others may develop pure fracture cleavage during late stages of the movement. There is, however, still another possibility : the internal shearing couples generated by bedding plane slip may act on fine-grained beds which are plastic and chemically reactive, *i.e.*, they are capable of easy recrystallisation. This would result in the local formation of slaty cleavage on planes controlled by the position of the *AB*-plane of a strain ellipsoid whose orientation is in turn governed by a combination of general external and local internal stresses, of which the internal may be the more important. Over a group of rocks, therefore, even if they do not differ greatly in character, we may get the development of two types of cleavage —mechanical or fracture, and chemical or slaty. Locally one may grade into the other. This has been noted in cases where fracture cleavage shows a curved or sigmoidal form tending to become tangential to the bedding planes. Recrystallisation has occurred where the deformation has been most intense, and the two planes of no distortion have closely approached the *AB*-plane of the ellipsoid, Fig. 49c. Their cleavage strikes will be similar, but the cleavage dips will vary, the slaty cleavage dip will be more nearly parallel to the axial plane of the fold.

The orientation of slaty cleavage produced in this way depends on the local orientation of the strain ellipsoid, *on the amount of local deformation at the time recrystallisation occurred.* Consequently it may not be perfectly oriented parallel to the axial plane of the fold. Local conditions by deflecting the external stresses may cause the cleavage to form a fan across the fold ; but the divergence or convergence of the fan would not be as great as that characteristic of fracture cleavage.

The production of slaty cleavage during the folding may lead to further complications. Though recrystallisation of the soft plastic rock converts it to a much more resistant one, the bed, once it has become a slate, is no longer an isotropic body : it is traversed by a multitude of planes of weakness, planes upon which slipping may occur as the rocks adjust themselves to the stresses. ‘ The plastic deformation of the slaty rocks may be accomplished by shearing rather than folding, relatively competent strata continuing to bend during periods when less competent beds yield by minute shear.’ (Balk, 1936, p. 709.) Folds in which this type of movement is dominant are known as *shear folds* in contradistinction to normal buckle or flexural folds (Hills, 1940, pp. 81–3 ; Knopf and Ingerson, 1938, p. 157 ; and Cloos, 1937, p. 56). The slaty-cleavage thus becomes puckered and wavy, the bedding, particularly at fold apices, becomes crinkled and discontinuous due to small scale faulting, and as the slipping continues the rock may recrystallise still further on the slaty cleavage planes so developing a phyllitic type.[1]

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[1] The ultimate state of shear folding is the development of rock-flow. Balk (1936, pp. 720-724) describes and clearly illustrates structures resulting from the plastic flow of marble which encloses brecciated fragments of more resistant beds.

The change in conditions visualised can also result in other phenomena. As folding continues the now brittle slate may suffer fracture cleavage which would cut across the earlier slaty foliation; examples are figured by Dale (1899, p. 209 and Pl. 28). This would cause the slate to break into elongated fragments of more or less rhombic cross-section, bounded by two parallel faces of slaty cleavage origin and two formed by fracture cleavage. A very similar effect may be obtained by the combination of original bedding fissility combined with an imperfectly developed cleavage. In either case the elongation of the fragments will be parallel to the *B*-axis of the ellipsoid, and will indicate the local tectonic pitch—*b*.

Continuation of adjustment movement on original fracture cleavage planes may also occur. Such slipping results in the original uncleaved flakes of rock between the fracture planes being in turn sliced until the whole rock had the appearance of a rough slate. Becker (1896) considers that it is along such fracture plane surfaces that all adjustment takes place, and that 'the energy of strain is converted into heat and this heat is developed exclusively along the flow surfaces [fracture planes]. In chemically unstable bodies this heat will manifest itself in the production of secondary minerals such as mica, and the new minerals will arrange themselves along the lines of flow. This action appears to me to constitute dynamo-metamorphism so far as such metamorphism attends direct pressure.'

Whether or not pure dynamic metamorphism is capable of developing true schists without assistance from external sources of heat or emanations is a debatable question which has been discussed by Read (1939) who reaches the conclusion: 'Whilst stress is admittedly the dominant factor in the production of low-grade metamorphic rocks, there is agreement that its effect is small in the higher grades, where the products of regional and thermal metamorphisms converge, high temperatures being in control. There is no correspondence between the degree of deformation and the metamorphic grade, unless it be one of the greater the deformation the lower the grade . . . . stress by itself is not enough.' (p. 17).[1] Evidence supporting this conclusion is based largely upon the effect of 'dislocation metamorphism' produced on thrust-planes or other zones of intense movement where there has been a general reduction in metamorphic grade of the rocks involved. In Unst, in the Shetland Isles, Read (1934, p. 680) has listed the mineral facies of the zone of dislocation metamorphism and has compared them with those of the original rock. He finds high-grade gneisses such as kyanite-staurolite-garnet rocks reduced equally with lower grade isochemical types such as chloritoid-chlorite-muscovite-schists to chlorite-muscovite schist. Locally biotite may persist in the dislocation zone ; other typical minerals are tremolite, epidote, zoisite, sericite, antigorite, and talc. All these minerals are equally characteristic of low-grade metamorphic types derived from unmetamorphised rocks.

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[1] 'Les actions dynamiques déforment: elles ne transforment point.' Pierre Termier (1903, p. 580).

This development of the same low-grade mineral assemblage downward from higher-grade schists and gneisses or upward from normal sediments is a form of metamorphic convergence characteristic of movement. It is strongly suggestive that though the heat developed on large dislocation zones be insufficient to retain the metamorphism above the chlorite-biotite-tremolite grade, it is nevertheless enough when generated by friction on innumerable minor shear planes, as in cleavage development, to raise the unmetamorphised shales, etc., to that grade, with the production of slates, phyllites, and possibly biotite bearing rocks.

Early low grade metamorphic recrystallisation may thus control the later development of higher-grade schistose structures, and the later recrystallisation will be guided by earlier cleavage formation. Thus Balk (1936, p. 714) has observed that ' the fabric of the shear-plane coatings is coarser and carries more, and larger, crystalloblasts than does the remainder of the schist ; the conditions for the growth of crystalloblasts were evidently better along these planes than elsewhere in the schist.' One type of cleavage may persist throughout, or it may become overprinted or even obliterated by a second—excellent examples are illustrated by Broughton (1946, Fig. 5, B, C and D, p. 8)—but the story will in general be much the same—the schistosity, the cleavage and the folding are all part of the same tectonic movement. It may be impossible to separate recrystallisation following slaty cleavage planes from that on fracture cleavage planes—additional movement may have caused them almost to converge together—but an understanding of the principles of their production can be of the greatest value when working on the structure of such crystalline rocks.

Should the movements responsible for the production of two cleavages have been of different character, that is from different directions, there would not necessarily be any degree of parallelism between the two structures. The later cleavage might thus cut across the earlier at any angle, and complete incongruity of structures would appear until the two were separated into their respective systems.

V. FRACTURE OF BRITTLE ROCKS

The production of cleavage in rocks discussed in the preceding pages has been based on the assumption that the rock was appreciably deformed before rupture occurred, *i.e.*, that under the slow steady application of forces by geological agencies the rock behaved as a more or less plastic solid. The orientation of the cleavage depended on the orientation of the planes of no distortion in a hypothetical strain ellipsoid. As the strength of the strained rock increases so does its resistance to deformation increase, and the strain ellipsoid which represents the amount of distortion becomes more and more stumpy, while the angle between the two planes of maximum shear becomes nearer and nearer to 90°. In nature the angle between cleavage and bedding behaves similarly and in massive beds cleavage is commonly developed only as a form of jointing. It is a widely spaced system and may not be readily recognisable as a fracture cleavage phenomenon at all.

Cleavage developed in interbedded grits and shales may thus show differences in orientation. The general cleavage strike remains more or less constant, but the cleavage dip varies markedly with the rock-type. An excellent example of this is to be seen in the Silurian rocks of the Austwick-Ribblesdale Area (King and Wilcockson, 1934) where the Austwick grits and flags occurring together are respectively poorly and well cleaved.

Cleavage development of this general type which can be resolved by the use of a theoretical strain ellipsoid is said to have been formed according to the '*Strain Theory*.' The position of the planes of shear in the rocks has been determined by the amount and nature of the deformation (known as *shearing strain*) that the rock has suffered. The direction of application or the relative magnitude of the forces which caused this deformation have hardly been considered in the discussion.

It is, however, well recognised that rocks do not break through shearing strain in many cases. Specimens compressed in the laboratory fracture on planes inclined at 45° *or less* to the direction of applied pressure (or maximum shortening); because of internal friction this angle may be as little as 30°. So true is this that Hartman's law in mechanics states that 'the acute angle formed by the shearing planes is bisected by the axis of maximum compression' (Griggs, 1935, quoting Bucher, 1920). Bucher's modification of this law to include ductile substances has been strongly opposed by Griggs who considers it should begin and end with the definition as given above.

Leith (1923, p. 34 ff.) and Swanson (1927) both fully realised that rupture of resistant, tough or brittle rocks such as grits, limestones or lavas under near surface conditions would occur before pronounced deformation of the rock had taken place, and that they would fracture along planes whose orientations obey Hartman's Law. I seem to recall in the pages of *The Outcrop*—the unofficial organ of the Department of Geology at the University of Wisconsin—a couplet on this very theme :

'Consider both angles, take that which is less,
And the line that bisects it's the maximum stress.'

'Both angles' refers to the acute and obtuse angles between intersecting joint planes.

Rock failure in this manner where deformation before rupture is not considered is referred to as failure according to the '*Stress Theory*.' The positions of the planes of maximum shearing stress are determined by the directions of the applied forces. In geology it is only under unusual circumstances that anything approaching an accurate estimate of the nature and direction of the applied or external forces acting on a rock can be made. The strain or deformation can often be measured, and fracture planes, cleavage and foliation show remarkable agreement with prognostications deduced from the theory of failure by strain. Application of the stress theory of rupture to structural geology is fraught with more difficulties, though experimental work has yielded far more information in support of this theory than it has done in the case of the strain theory.

A convenient method of considering the relative magnitudes and directions of forces acting on any point is to represent them by means of a *stress ellipsoid* (Fig. 51) analogous to the strain ellipsoid, but in which the lengths and directions of the three axes are proportional to the principal stresses acting at the centre. Thus for the stresses on any particular rock which is not being acted on by tectonic forces the figure is that of a sphere of which the diameter is a measure of the retaining pressure—hydrostatic force—at the particular point under consideration. Application of horizontal pressure in a vice-like manner would then be represented by elongation of the diameter colinear with the direction of pressure : the sphere would thus become a prolate spheroid, or elongated ellipsoid of revolution. In the case of a rock buried in the crust ; however, there will be retaining pressures to consider. These act at right angles to the line of application of pressure. Of these forces one will be in the direction of easiest relief, it will be the least axis. The other will be that of the original retaining pressure *plus* some component of the external applied stress, this will be the intermediate axis. Unlike the case of the strain ellipsoid there is no constancy of volume to be maintained. For purposes of reference, therefore, we can name the axes in our stress ellipsoid :

ZZ — the longest—represents the applied pressure—$P_{max.}$
YY — the intermediate axis, the direction of retaining pressure.
XX — the shortest axis—the line of least pressure ; which is, relative to the other two, the direction of tension—$P_{min.}$

With this nomenclature in mind it is possible to visualise a relationship between the stress and strain ellipsoids, Fig. 51.

ZZ — the line of applied pressure (*PP*) corresponds with the axis of greatest shortening *CC*.
YY — the intermediate axis corresponds to *BB*, *i.e.*, the *b* direction.
XX — the axis of least stress, *i.e.*, tension, corresponds to *AA* the direction of elongation.

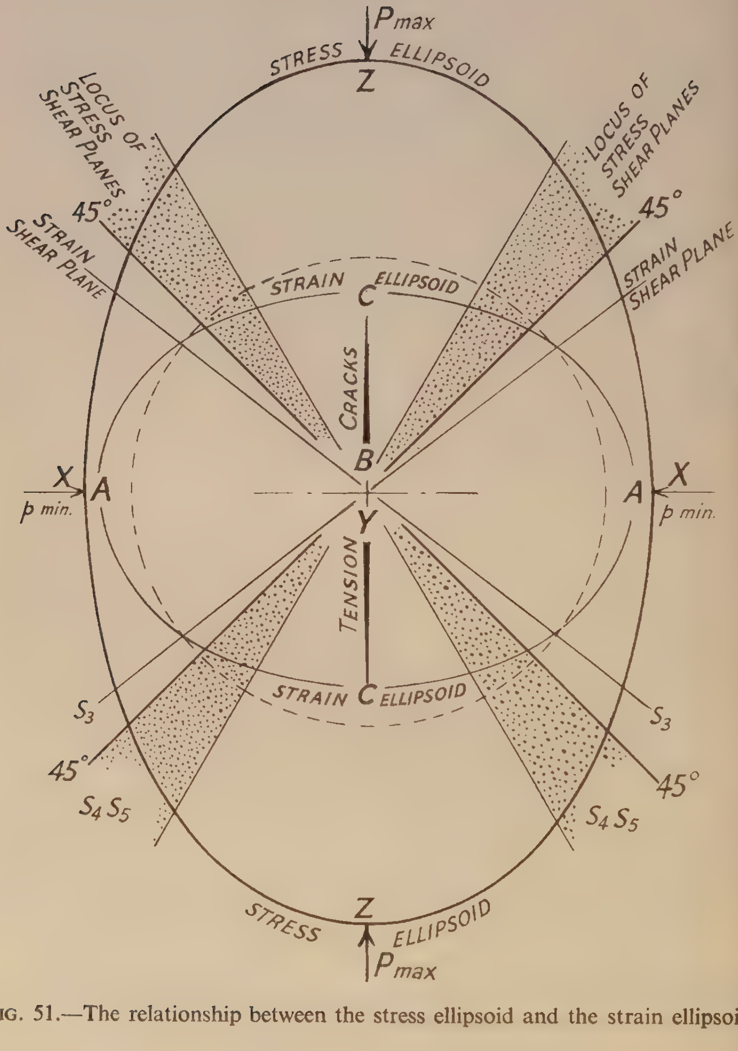


FIG. 51.—The relationship between the stress ellipsoid and the strain ellipsoid.

The two ellipsoids are at 90° to each other about the common *YY* or *BB* axis. The circular sections of the stress ellipsoid do not represent, as in the strain ellipsoid, planes of maximum shear, but we know from experiments on brittle rocks that these lie at less than 45° to the direction of maximum compression. It is obvious from Fig. 51 that the planes of maximum shearing strain, S_1S_3 and loci of maximum shearing stress S_4S_5 do not correspond, and we are faced with alternative sets of directions of shear.

The field evidence in cases where rocks have cleaved according to the strain theory is clear, and from it a straightforward and logical argument can be built up and used in other cases. Where rocks have failed on planes which have to be explained by the stress theory it is often very difficult to correlate fracture directions with the general structure, though with known stresses in the laboratory or in engineering practice it is relatively straight-forward. So marked is this difference in rock-behaviour that Swanson (1927, p. 216) suggests a rule ' that in incompetent rocks the pattern of slip joints be interpreted in accordance with the strain theory, and that in competent rocks the patterns be used with caution.'

However, the relationship between the theoretical stress and strain ellipsoids, Fig. 51, permits us to consider in a very tentative manner the probable development of shearing stress fractures in a folded bed. As already shown the forces acting on the bed will be dominantly in the form of a couple working upwards toward the anticlinal crest, combined with a directed pressure more or less oblique to the dip of the bedding. We have seen how this stress system distorts the rock if the bed be incompetent ; so, by first considering how a hypothetical strain ellipsoid could be oriented under such conditions we can secondly fit a stress ellipsoid at 90° to it and see how the planes of maximum shearing stress might be located.

The position of a typical strain ellipsoid in a bed under conditions of folding is shown in Fig. 52a, and with it are shown the cleavage planes developed in response to the shearing strain. Possible tension fractures (*T*), which lie normal to the direction of elongation have been indicated. The relationship of fracture cleavage and tension is illustrated in Plate 23. The stress ellipsoid normal to this strain ellipsoid is shown in Fig. 52b : the complex joint pattern that might be expected parallel to the planes of maximum shearing stress shows little direct association with the fold structure, and it may quite possibly be rendered even more involved if fracturing parallel to the tension joint direction (*T*) is also developed. The recognition of such tension fractures in the field is often of considerable assistance, as their orientation is the same in the case of stress rupture as it is for strain, Fig. 51.

Experimental fracturing under conditions very similar to those produced by folding has been done at the University of Wisconsin.

Leith (1923, Fig. 11B, p. 37) illustrates the result of shearing a block of limestone. The fracture pattern, reproduced in Fig. 52c, compares very closely with that theoretically derived and shown in Fig. 52b, see also Swanson (1927, Fig. 15).

An important application of the ' stress ' theory to rock-fracture is the development of *Shear Cleavage* (Mead, 1940). This occurs in beds which, after they have once been folded and possibly cleaved, have been further subjected to stress. It is the result of local failure by stress shear of the folded rock-mass as a whole due to *external* compressional forces. ' There seems to be a reasonable analogy between the orientation of thrust-faults and shear cleavage in their angular relationship to causal stresses.' (Mead, 1940, p. 1018–19.)

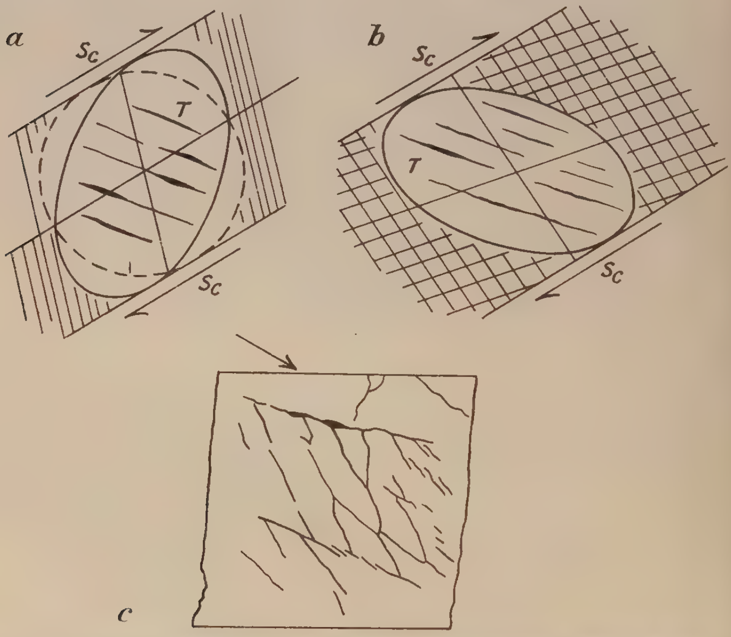
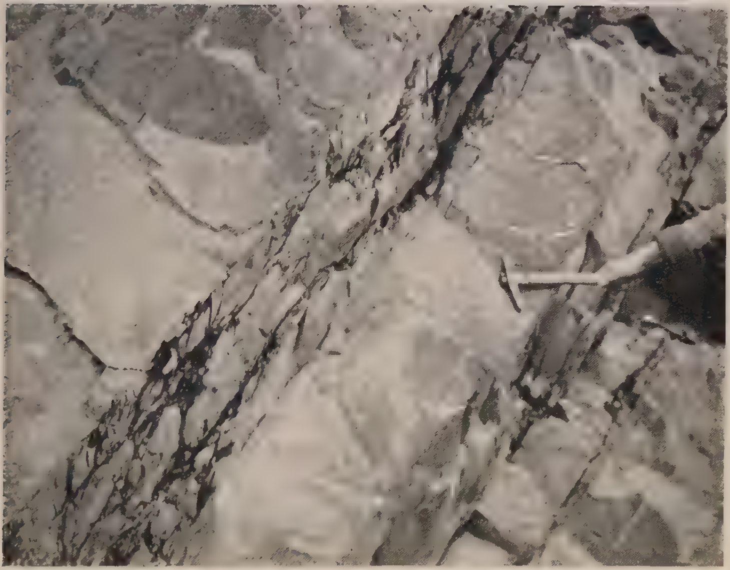


FIG. 52.—The relationship between fractures developed by shearing strain (a) and by shearing stress (b) in a bed subjected to a couple S_c S_c. In (c) are shown the fractures produced in a deformed block of limestone, after Leith (1923, Fig. 11B).

A striking example of this relationship was given by Muff (Maufe) in 1909. He demonstrated the production of strain slip cleavage cutting phyllites as being the result of failure on stress-shear planes (S_4–S_5, Fig. 53) symmetrically oriented in respect to the axial



Fracture Cleavage in thin bedded mudstones lying between massive grits in which tension cracks (white, parallel to the hammer handle) have developed. The left hand side move upwards, and the main synclinal structure lies away to the left of the photograph; compare with Fig. 52a.

Entrance to Arcow Wood Quarry, near Horton-in-Ribblesdale. Photo. by Mr. A. B. Harman.

[*To face p.* 288.

plane of a fold. He considers (p. 16) that ' an important factor, which conditioned the change in the mode of deformation, *viz.*, from slaty cleavage to strain slip cleavage, is a greater rigidity of the phyllites, or rather a loss of capacity to flow.' Muff's diagram (Fig. 3) on which Fig. 53 is based shows the later cleavage planes making an angle of about 45° with the fold axial plane, *i.e.*, to the *Z* or *C* ellipsoid axes of Fig. 51.

According to Mead (1940, p. 1010) shear cleavage shows as roughly parallel closely spaced fractures on which platy minerals have developed or have been dragged (see also Muff, 1909, Fig. 2), and ' . . . where spacing is unusually close shear cleavage may simulate and be easily confused with flow cleavage . . . ' Each shear surface is considered a minute thrust fault accentuated by recrystallisation. ' It is not homogeneously distributed through the rock, but is spaced into parallel surfaces, each of which is a surface of shear failure with some degree of displacement, however minute . . . . ' (Mead, 1940, p. 1018.) A general description which closely matches Muff's observations.

Lovering (1928) is of the opinion that normal fracture cleavage is developed by much the same mechanism. That is, it was not formed by a shearing couple caused by bedding-plane slip, but by failure due to compression along stress-shear planes towards the close of the main folding episode.

The strike of shear-cleavage planes will only be parallel to that of the fold axial planes when the fold pitch is horizontal, and then if the folding and cleavage phenomena are the results of the same deformation. Even if the cleavage is ' *congruous*,' *i.e.*, developed by the same agency as the folding, it will not strike parallel to the axial planes if the main structures have measurable pitch. The intersection of the shear cleavages, *B* in Fig. 53, will be parallel to the fold pitch *b* under such circumstances ; but the strike directions of the cleavages themselves will meet at some point *O*. The direction of cleavage convergence is opposite to that of the closure of the fold. The same, but to a much lesser extent, is true of ordinary fracture cleavage. Despite this discrepancy of directions the combination of bedding dip and strike on one hand, and those of the shear cleavage on the other, gives a line of intersection b_5 between the two structures which is not far from parallel to the general fold pitch *b*. It gives a good first approximation to this last direction. The intersection of shear cleavage with slaty cleavage as shown by b_4 will, however, be closer to the true pitch.

Mead (1940) also finds that ' where the direction of easiest relief is lateral (horizontal), steep angled thrust faults are developed with horizontal displacement striking somewhat less than 45° to the right or left of the direction of compressive force . . . ' and hence that ' . . . shear cleavage with vertical dip may develop.' Intermediate cleavage orientations between these two extremes are also possible, and 'where the direction of easiest relief is inclined the dip of shear cleavage should be correspondingly intermediate between 45° and 90°, with a shift in the strike directions called for by the geometry of the situation." (p. 1019).

Such cleavage which shows no direct connection with the folding movements must be considered '*incongruous*.' Until its relationship to the major structures is established difficulties in its use in the solution of the structural pattern will doubtless be encountered.

The development of platy minerals along planes which would otherwise be termed fracture cleavage is according to Mead (1940, p. 1020) enough to suggest 'that the cleavage should have been interpreted as a shear cleavage rather than fracture cleavage.' This distinction seems to me rather to confuse the issue, and it seems desirable to retain the term 'shear cleavage' for the larger scale phenomenon discussed above. Broughton (1946, p. 13) accepts Mead's suggestion and 'believes that shear cleavage can be a transitional stage between flow and fracture cleavage.'

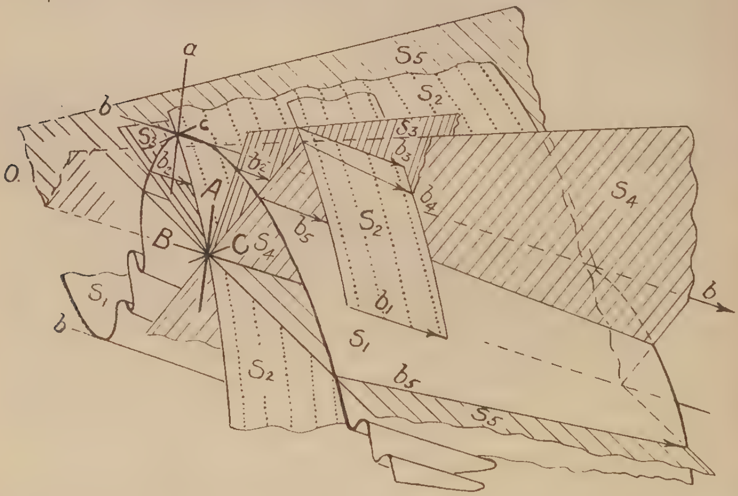


FIG. 53.—THE RELATIONSHIPS OF BEDDING AND CLEAVAGE SURFACES AND LINEAR ELEMENTS TO A PITCHING FOLD.

a, *b*, *c*, Fold co-ordinates. *A*, *B*, *C*, Axes of the strain ellipsoid for the system. S_1, Bedding surface. S_2, Axial plane and slaty cleavage surfaces. S_3, Fracture cleavage surfaces. S_4, S_5, Shear cleavage surfaces. *b*, True pitch of the fold. b_1, Intersection of bedding and slaty cleavage : S_1–S_2. b_2, Intersection of bedding and fracture cleavage : S_1–S_3. b_3, Intersection of slaty and fracture cleavages : S_2–S_3. b_4, Intersection of slaty and shear cleavages : S_2–S_4. b_5, Intersection of bedding and shear cleavage : S_1–S_4 or S_5.

VI. DRAG FOLDING

Closely associated with the phenomena which produce cleavage in rocks are those which cause minor folds and contortions of strata on the flanks of major structures. These were recognised and illustrated as early as 1853 by De la Beche (p. 648). The importance of such folds has been demonstrated by Derry (1939), and their formation is discussed in most modern books on structural geology (Billings, 1942 ; Hills, 1940 ; Nevin, 1936 ; Leith, 1923). The term ' drag fold ' implies a fold which is not the direct result of the application of an external stress. It is a secondary, minor phenomenon formed by the rucking up of usually thin bedded strata by the frictional drag developed within the beds as a whole during the major folding episode. Unfortunately drag folds are not always associated with straight-forward folding, they may also be produced by drag movements on faults or shear zones, but from their orientations the nature of the movement from which they originated may be deciphered.

Derry (1939) classifies drag folds as :

(a) *Dependent drag folds* which are directly produced by the major folding, and
(b) *Independent drag folds* which are the product of other movements and hence show no relation to the major fold structures.

Hills (1940) uses the terms *congruous* and *incongruous* in the same senses.

Dependent or congruous drag folds are, like fracture cleavage, the result of upward movement directed towards the tops of anticlines. Thin strata are dragged up towards the anticlinal axis by the frictional drag exerted by overlying beds. Well developed folds will show clearly the direction of relative movement, Fig. 12, whence, as in the case of fracture cleavage, it is possible to state whether the beds are right way up or inverted.

Dependent drag folds are additionally useful in that their axial planes and pitch generally agree with those of the major structure on the flanks of which they lie—Pumpelly's Rule (Pumpelly *et al*, 1894). They give an even more direct indication than cleavage does in this respect. It should, however, be realised that isolated contortions may be deceptive and should be treated with caution until supported by further evidence. In most cases major fold structures have a relatively gentle pitch, up to about 30°, though exceptions may occur. Hence dependent drag folds may be expected to pitch at similarly low angles.

Independent or incongruous drag folds on the other hand are related to faulting movements or to large scale shearing which is not necessarily connected with the regional folding. Thus in the North-West Highlands the drag folding of the Torridonian and Cambrian strata, which often occurs in close association with the imbricate structure, shows a relatively flat pitch lying at right angles to the direction of overthrusting. Where, however, one is dealing with more or less horizontal movements along steeply dipping faults, the drag folds formed at right angles to the direction of movement would pitch steeply. The careful plotting of the orientation of such folds can, therefore, be of value in assessing the nature of lateral movements which extend over a considerable width of country without necessarily being confined to a narrow shear-zone.

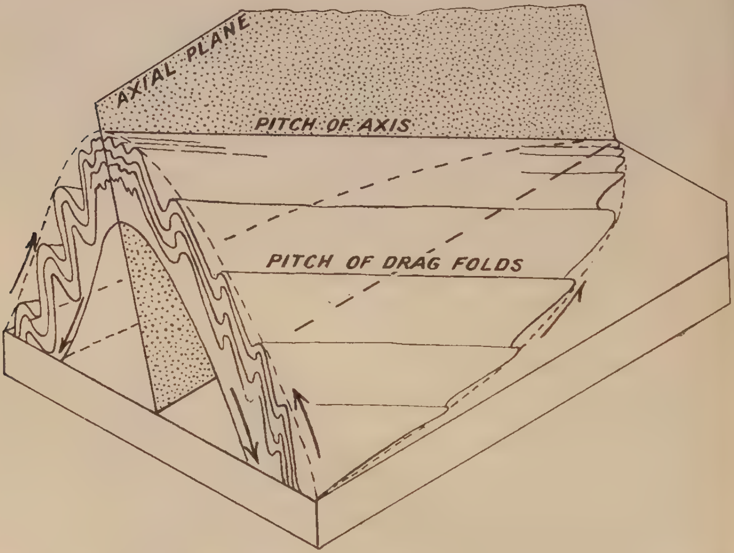


FIG. 54.—The relationship between the pitch of drag folds and that of the major structure.

VII. SCHISTOSITY AND LINEATION[1]

A discussion on the cleavage problem and the use of cleavage in the field cannot close without some comment on schistosity which is, as it were, the next step up the metamorphic ladder. Fortunately a modern review of the whole problem of regional and dynamic metamorphism is available in H. H. Read's Presidential Address to the British Association (4th September, 1939) on ' Metamorphism and Igneous Action.' Read has (p. 28) ' belittled the role of the dynamic factor in regional metamorphism,' that is in the higher grades : but he considers ‘ that in the lower grades it must be of considerable importance.’ To him, and to those who agree with him, high-grade metamorphism is dominantly the result of recrystallisation under the influence of mobile solutions and heat of magmatic or migmatic origin. That there is a steady chemical change during the transformation from shale to schist has been clearly demonstrated by Brammall (1933) whose plotted analyses show the latter rock-type to be richer in normative albite at the expense of normative orthoclase than the former. Mobile solutions whether exudates (squeeze-outs) or of exotic origin will become concentrated in all pre-existing planes of parting, fracture, or weakness in the rock, and recrystallisation aided by the presence of such augmented fluids will be accelerated and encouraged along these planes (Balk, 1936, p. 714). The result is the reproduction of pre-metamorphism structures, such as bedding lamination, with or without early formed secondary foliations, in a more coarsely crystalline form. Such control of schistosity development is referred to as mimetic crystallisation, or *Abbildungskristallisation* of Sander (1930).

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[1] A very useful memoir on this subject by Ernst Cloos (1946) has just been published by the Geological Society of America. Not only does the author discuss the production of the many forms of lineation, but he gives a most valuable and comprehensive survey of the literature concerning it.

Such recrystallisation would normally be a late stage process in the tectonic or metamorphic history of an area, and the structures observed could be used in the same general way as those described in the earlier sections of this paper. Examples of bedding-plane recrystallisation are common in the Moine rocks of Scotland, and an example of the utilisation of fracture cleavage planes as passages for emanations associated with an injection complex in the Ross of Mull is shown in Bosworth (1910, Fig. 3). Similarly in Dutchess County, New York, ‘ . . . the metamorphic rocks have been thoroughly soaked in “ hydrothermal ” solutions the main thoroughfares of which have been shear planes [intimately connected with fracture cleavage, Balk, 1936, pp. 709–713] enhancing thereby the schistosity and imparting to the rocks a markedly foliated character ’ (Barth, 1936, p. 807).

The introduction of heated solutions into rocks which are still undergoing folding promotes the development of schists of complex character. The problems presented by these rocks form the main theme in the modern study of metamorphism and structure which is referred to as *Structural Petrology* or *Petrofabrics* (Fairbairn, 1942 ; Knopf and Ingerson, 1938 ; Sander, 1930). The effect of energising the interpore solutions of the rocks not only promotes crystal growth, but also reduces friction within the fold complex as a whole. In consequence deformation is much exaggerated beyond that appearing in rocks on the margins of orogenic zones. Structures normally seen in the field in the latter areas may be rendered undecipherable or distorted beyond recognition by movement and recrystallisation. This last, however, tends to follow such planes—referred to as *s*-surfaces—as might have been formed by bedding, shearing or flattening, early or late in the metamorphism, by much the same mechanisms as fracture and slaty cleavage.

The great translations which occur in these rocks, the excessive movements, all combine to complicate the rock pattern produced. The whole fold-system is moving and shearing within itself at this stage. Bailey (1938) even considers that major units of a complex may be rotated upon themselves forming ' Eddies.' We also know that porphyroblasts have been rolled forward as they grew, *e.g.*, ' snowball ' or ' pinwheel ' garnets, and attempts have been made to calculate the actual displacement responsible for the rotation. Estimates vary ; the average movement is three times the thickness of the strata involved, with a maximum of 5.6 times (Fairbairn, 1942, p. 79). These great horizontal movements combined with, as they must be, internal torsions, effect the orientation and shape of the theoretical strain ellipsoid for the deforming rocks. While the planes of maximum shearing strain are rotating and tending to close (like a pair of scissors) the ellipsoid itself is being rotated on its *B*-axis. The result is that one shear plane swings over a wide arc while the other swings over a narrow one. The intensity of shearing strain will thus be more concentrated on the latter plane than on the former. According to Becker crystallisation will follow the direction of the arc of lesser movement. Others consider it more probable that one plane may be arrested in its sweep by some earlier formed surface and the shear concentrated on that surface (Schmidt's hypothesis).[1] Both possibilities are discussed by Fairbairn (1942, pp. 91–2).

The result of this unequal distribution of shearing strain is to promote crystallisation at different rates in the shear directions. To these can be added the influence which original bedding fissility and perhaps that of early slaty cleavage would have on the localisation of crystal growth. These together leave us with some four plane directions on which schistosity may develop—there may even be more. In consequence the formation of platy minerals is not necessarily confined to one planar direction. One plane forms the optimum growth zone, and parallel to it will be the plane of schistosity ; but minerals will develop on the other planes too, perhaps at but a slight angle to the main direction. The intersections of these growth orientations combined with possible slip on one of the other shear planes will show as *lineations* running across the schistose surface. These may be well marked, strong corregations or they may be so faint as to require careful study before they can be identified.

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[1] Thus if we consider the ellipsoid shown in Fig. 47c, and imagine it being both rotated clockwise and at the same time being further compressed, it is obvious that such a combination would readily bring S_3 into a position of sub-parallelism with the present *AB*-plane of slaty cleavage (S_2). The position of the later fracture cleavage would, in such a case, coincide with the earlier axia plane cleavage, and subsequent schistosity would develop most strongly along that plane.

The pitch of this lineation is important. It marks the intersection of the shear planes with each other, with the bedding or with the *AB*-plane (slaty cleavage) of the ellipsoid (b_1–b_5, Fig. 53). These intersections lie along the *B*-direction of the ellipsoid, which as we have already seen (p. 289) marks the tectonic pitch—*b*. Fermor (1924, p. 560) noting the relationship between lineation and fold pitch states ' . . . an excellent index to the local pitch is provided by these grooves and streaks, and to anyone attempting to unravel the structures of the Archean rocks it becomes as important to observe and record the pitch phenomena as it is to record dip and strike.'

Other phenomena also indicate this important direction ; when early formed schists or slates are rolled forward they may become wrinkled, rucked or drag-folded, or cut by secondary cleavage. This must not be confused with bedding folding : it is a deformation of the secondary structure. Where the later movements are similar to or are continuations of the earlier ones the lineation so formed will indicate the local tectonic pitch. Thus in the Shetland Islands Robertson (1938) found that lineation on foliation planes is ' nearly constant in direction and in inclination to the horizontal over areas of appreciable lateral extent ; and where it varies it does so in a continuous manner, except where interrupted by post-foliation faults. The direction of the lineation was in every case found to be the same as the axial direction of the small scale contortions of the schists, where such contortions are to be seen.' Oblique later movements may, however, seriously modify the relationship between major and minor structures. Examples of early and late cleavage formation are to be found in Clough, 1897 ; Wright, 1908 ; Broughton, 1946.

Lineation may also be shown by elongation of elements in the schists, such as inclusions or crystal aggregates. Individual rod-shaped crystals—amphiboles or tourmalines—formed during the movement phase may behave similarly. Ernst Cloos (1937, p. 70) discussing the elongation of mineral patches and stretching of particles which were originally spherical states that ' . . . the most frequent orientation is parallel to the axes of the folds and, therefore, parallel to the *b*-axis of the system.' He then gives and illustrates (1937, pl. vii) examples of deformed conglomerates individual pebbles of which ' . . . may attain a length of 20 times their diameter and resemble cigars or torpedoes ' (see also Cloos, H., 1936, Fig. 266). Additional support is given by the crush-conglomerates of the Isle of Man (Lamplugh, 1895), where passage beds between grits and argillaceous strata have been highly contorted, cleaved and brecciated by interformational movement. The individual fragments of the harder beds may be sliced and angular, or they may have been rolled forward, and become smoothed, sheared, and rounded. There is no doubt as to their tectonic origin, and Lamplugh found that ' there is a very general elongation of the inclusions in the direction of strike . . . . ' He was, however, uncertain whether or not this was caused at the time of their formation or by later movements.

In contradistinction to lineation parallel to the tectonic trend *b* is the fact that ever since some of the earliest investigations of the cleavage problem an ' elongation in *a*,' *i.e.*, in the direction of the movement and at right angles to *b* has repeatedly been recorded. It is referred to in the earlier pages of this paper.[1] It may show as striations caused by bedding plane slip, actual deformation of inclusions in the direction of translation, etc., or even the development of elongated mineral blebs or patches during the movement (Broughton, 1946 ; Balk, 1936). Andrew Leith (1937) supporting this, the strain ellipsoid concept of deformation and elongation, argues that ' . . . without leading to utter confusion, one cannot say that the longest axis of strain is really shorter than the intermediate axis of strain.' An observation which is very difficult to refute !

The evidence summarised above indicates that elongation or lineation in either *a* (the direction of translation) or *b* (the tectonic trend) can occur. The explanation of the two opposed phenomena appears to me to depend on the degree of deformation that has occurred in the rocks. Up to a certain stage the distortion and directions of shear can be visualised and correlated by means of the strain ellipsoid. In this stage the movement in the rocks is comparable to *laminar flow* in a fluid, and elongation when it can be observed will be parallel to the *A*-axis of the ellipsoid and normal to the *B*-axis. Recrystallisation of the rock, be it mimetic or during deformation, will preserve or accentuate this ' elongation in *a*.' With increase in the amount—and probably the rate—of movement, combined with internal shearing and rotation, as in the case of the development of crush-conglomerates (Lamplugh, 1895), uniform conditions no longer hold. Roughly equidimensional elements, *e.g.*, garnets, will be rolled forward. Elongated elements will be twisted and rolled into or will crystallise in a position with their axes of elongation normal to the direction of translation, like spindle shaped pebbles rolling down the bed of a stream. Platy minerals will grow along, remain parallel to, or be twisted into planes of optimum development. They may suffer small scale drag-folding. The movement is now analogous to *turbulent flow*. The main shear directions probably still persist throughout the mass of rock as a whole. Within certain beds they may be the controlling factor guiding recrystallisation ; but in other units rotation can equally well be the dominant characteristic of the distortion. Knots and aggregates can therefore be pictured as being rolled out, as a ball of plasticene can be rolled out between the hand and the table, and elongation with recrystallisation occurs parallel to the local tectonic strike *b*.

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[1] See Cloos and Hietanen (1941, pp. 83–4) referred to on page 265.

It is in rocks such as these, which have suffered complex deformation and metamorphism, that the microscopic examination by means of the Universal Stage and the plotting of the mineral orientations on a statistical basis have yielded so much information. By these methods the fabric of the rock can be analysed, and successive stages in its metamorphic history can be correlated with tectonic movement. From the examination of the rock-fabric the *b*-direction in a tectonically deformed rock—a *tectonite*—can usually be identified, even if it is not visible in the field. Similarly lineations in *a* or in *b* may be separated. Thus by fabric studies Phillips (1937) was able to confirm Read's (1926) conclusions—reached in the field—that the mullion structures of the Moine Schists were formed by an early, probably Pre-Cambrian movement giving a lineation in *b*, accentuated later by an elongation in *a* produced by Caledonian movements acting approximately at 90° to the former.

The study of the rock-fabric—Petrofabrics, Structural Petrology, or Gefügekunde, Sander (1930), Knopf and Ingerson (1938), Fairbairn (1942)—is a natural development from the normal methods of study of metamorphic and structural geology. It is rapidly becoming a recognised and important part in the investigation of complex areas ; but it must be considered ancillary to field mapping, it can never replace it. The results, however, can be exceedingly valuable, and the evidence obtained by such painstaking methods yields information which cannot be found in the field alone even when aided by ordinary microscope technique. Unfortunately, as is inevitable in the growth of a new branch of a science, a formidable terminology has developed while it has progressed, and the interpretation of the results in the form of contoured statistical diagrams showing mineral orientations is difficult of comprehension to the layman. Nevertheless, as in the earlier days of geology when geologists were being driven to learn the technique of the microscope and its implications, so in the near future shall we have, at least, to understand and appreciate the results that can be obtained by the 'petrofabricists.' Fortunately good introductory descriptions of the methods and interpretations of the diagrams are now to be found in modern text-books of structural geology (Hills, 1940 ; Billings, 1942 ; and Cloos, E., 1937). Meanwhile even the unitiated field geologist can do much by observing the megascopic structural features of his areas and their relationships, particularly if he realises that 'every structure in a rock is significant, none is unimportant, even if at first it may seem irrelevant' (Cloos, E., 1937, p. 49).

In this paper I have tried to give an account of the status of cleavage in structural geology. Some of the theories advanced may not meet with uniform approval : my gospel may be other people's heresy. If it produces pertinent discussion which will add to our knowledge of geological structures and their formation I am well content. In conclusion I would like to re-echo Sedgwick's words on the same subject : ' . . . so far from thinking I have exhausted the subject, I rather wish some parts of this paper to be regarded as mere hints, to be followed out by better and more extended observations.' (1835.)

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DISCUSSION

Mr. W. H. Ward expressed his thanks to Dr. Wilson for his very interesting paper. The subject was a very difficult one to study in the field, and Dr. Wilson had dealt with it in a most lucid manner. Personally, he had never read any of the geological writings on cleavage, but, as an engineer whose livelihood was producing fracture cleavage in samples of argillaceous sediments, he had always interpreted the cleavage structures in the field from his knowledge of the theories of elasticity and plasticity. The Author had therefore provided him with a good stimulant and he would go back into the field with greater confidence and study the intricate strain patterns in rocks more deeply.

Reference had been made to the standard concrete cube test. This test was entirely arbitary and was only used as an index to contral quality. The development of fracture cleavage was restricted in the cube, because the planes of fracture wanted to develop at about 30° to the axis of maximum principal stress, and this the geometry of the cube did not allow. The American standard was, in fact, a long cylinder which gave strengths about two-thirds that of the cube. In general, it is found that the fracture cleavage, or shear planes, are inclined at angles varying between about 30° to 45° to the axis of maximum principal stress. For example, with a heavy fat clay the planes develop at about 45° and as the proportion of sand is increased the angle decreases down to about 30°, *i.e.* it becomes more frictional. Dr. Wilson illustrated this changing angle quite clearly in an argillaceous sediment whose sand content varied across the bed.

The Author said that fracture cleavage planes could be inclined at angles of greater than 45° to the axis of maximum principal stress. This he thought was impossible, and the explanation was surely that the maximum principal stress was along the other axis. One had to be careful when interpreting very local stress-strain phenomena in relation to the direction of thrust on the structure as a whole, because, in general, the directions of maximum principal stress changed continuously throughout the structure depending on the external restraints.

Mr. G. Theokritoff stated that he observed a rather interesting case of the relative movement of bed over bed in the Corrie Limestone. At Corrie, Isle of Arran, in an almost continuous series of exposures along the strike, the Corrie Limestone is seen to consist of beds of limestone largely made up of the shells of *Productus giganteus* alternating with beds of the more typical massive limestone. In a small monocline, the stress has been taken up in two ways; by the beds sliding over each other which resulted in slickensiding between the beds, and by flow in the limestone the effect of which is observed in the resultant elongation of the *Productus* shells parallel to the bedding planes. In this example, the slickensiding and elongation are at right angles to the pitch of the monocline.

Dr. J. E. Richey wrote : " The Author has been so kind as to allow me to read the MS. of his paper, and I wish to congratulate him upon the lucid and concise, yet comprehensive, way in which he has dealt with the complicated subject of cleavage. The paper should be of great value at the present time, both to those who have not followed the subject in all its aspects and to others, like myself, who may have found some difficulty in steering a course through the recent American literature.

" There are several areas in the British Isles where the technique of cleavage may be applied to advantage, the largest probably being the Scottish Highlands. Perhaps I may venture to refer to a district there with which Professor Kennedy and I have been particularly concerned during recent years. In the Moine Schists of Morar I have lately had to deal with structures which, I believe, represent metamorphised fracture cleavage, the cleavage having been formed both locally in relation to congruous drag-folds and regionally in direct relation to the great Morar Anticline. Further, the trace of the regionally developed cleavage appears as lineation upon the bedding planes of the mica-schists, and the lineation follows the *B* direction, and, in its inclination, the pitch of the fold. Other directions of lineation, especially in relation to smaller folds, also occur, as has been realised especially by Professor Kennedy, but the main cleavages and lineations show the relations indicated above. If their suggested origin is correct, the prospect of a wide field for further research would seem to open out, and it is evident from the Author's descriptions that the recognition of similar cleavages elsewhere, now fixed in mimetic crystallisations, should provide a useful means of attack upon local tectonic problems in the Highlands."

The Author, in reply, stated that Dr. J. E. Richey's remarks regarding observations of mimitic crystallisation on fracture cleavage planes and of lineation in *b* parallel to fold pitch were of the greatest interest. The Morar anticline (Richey, J. E. & Kennedy, W. Q. (1939), *Bull. Geol. Surv. G.B.*, No. 2, p. 26) is a structure which was worked out by straight-forward geological mapping. The congruity of the secondary minor structures with the proved major fold structure is a valuable encouragement towards their use elsewhere in this field. He himself, this summer, whilst working on the Moines in the Ross of Mull found that a strong lineation in the schists, the pitch of isoclinal folds and of drag-folds all showed remarkable parallelism. It is very gratifying to learn from one with Dr. Richey's experience in mapping metamorphic rocks that the phenomena discussed here may have a useful application in the elucidation of the Scottish Pre-Cambrian.

He would like to take this opportunity of acknowledging his thanks to Dr. Richey for the discussion of several points in the paper, and for the kind comments he makes in regards to it.

Mr. W. H. Ward's contribution to the discussion is exceptionally valuable because it clearly illustrates the fundamental difference in outlook between the engineer and the geologist. The former recognising the development of planes of maximum shear up to 45° with the axis of maximum principal stress will not admit their formation at any greater angle to this axis. He can produce these cleavage directions in the laboratory at will, and when he knows the nature of the material to be tested he can foretell with remarkable accuracy the angle that will be formed between the shear planes. His calculations are based on the Stress Theory of rupture. The geologist, however, finds that the orientations of shear cleavage planes observed in the field do not agree with those that would be expected according to this theory, but they *do* conform when the Strain Theory of rupture is applied, and when the theoretical shear planes are considered as being at angles of over 45° to the direction of greatest shortening.

In the laboratory and at relatively shallow depths in the earth's crust rock fracture undoubtedly obeys Hartman's Law. But where movement has occurred at greater depths we find the rocks deformed—often without rupture—in a manner that would be considered impossible if we depended on their physical properties and behaviour as determined by laboratory tests and near-surface observations. The effects of retaining pressures by superincumbant material possibly combined with the time factor appear to be such that in considering the development of fracture cleavage in folded rocks the Strain Theory of rupture seems to give a better picture and a closer approximation to what has occurred than can be obtained by application of the Stress Theory.

The point referred to by Mr. Ward is already discussed in Section V of this paper, and further views on this controversy can be found in Swanson (1927), Griggs (1935), Leith (1937) and Fairbairn (1942, Chap. vi).

The Author is very grateful to Mr. Theokritoff for bringing to his notice the example he describes of elongation and lineation in *a*. An occurrence, such as this, which is in an area often visited by geological parties is of considerable value, as well as adding " versimilitude to ' this ' otherwise bald and unconvincing narrative."

NOTES ON WEALDEN FOSSIL SOIL-BEDS

By P. ALLEN, M.A., B.Sc., Ph.D., F.G.S.

(Weald Research Committee Report No. 34)

I. INTRODUCTION

FOSSIL soil-beds, containing the nearly complete subterranean stem and root systems of plants " growing " *in situ* [**6***], are now known to occur at no less than five different horizons in the Lower Wealden rocks of Sussex, Kent and Surrey. In addition, basal remnants of the rootlet-bearing portions of at least five others appear to have been located. Some of the beds are useful for detailed mapping and yield further evidence regarding the nature of the Lower Wealden environment. It is, therefore, desirable to give an interim account of them.

II. NOMENCLATURE AND SEQUENCE

Each soil-bed is here designated by the name of the locality where it is best developed and (where possible) by the name of its dominant plant.

The rootlet-beds are unnamed for the present. Most of them yield insufficient data for lateral correlation and none yields material suitable for precise botanical determination. Combined with the smallness and scarcity of the exposures, this lack of individuality makes the number of original soil-horizons, which they represent, very doubtful. The figure given (five) is, therefore, only a minimum.

Both soil- and rootlet-beds occur in sediments ranging from clay and shale to fine sandstone. Their relative stratigraphical positions within the lithological subdivisions of the Lower Wealden are as follows :

Grinstead Clay
    (e) Balcombe *Equisetites lyelli* Soil-Bed.
        Rootlet-bed.

Lower Tunbridge Wells Sand
    (d) East Grinstead Soil-Bed.

Wadhurst Clay
        Rootlet-beds (at least two).
    (c) Broad Oak ? *Equisetites* Soil-Beds (at least two).
        Rootlet-bed.
    (b) Brede *Equisetites lyelli* Soil-Bed (= ' Lower Wadhurst Soil-Bed ' [**6**]).

Ashdown Beds
    (a) Tonbridge *Equisetites* (? Soil-) Bed (' Ashdown Sand ' facies).
        Rootlet-bed (' Fairlight Clay ' facies).

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* For List of References see p. 312.

The absence of records from the Upper Tunbridge Wells Sand is not significant, for this formation has yet to be searched intensively. One hopes that Judd's description [2] of a Sphenopteris-like fern "growing" in profusion in the 'Hastings Sand' at Stammerham (near Horsham, Sussex) is a happy augury for the future examination of higher horizons.

III. THE SOIL-BEDS WITH PLANTS

(a) The Tonbridge *Equisetites* (? Soil-) Bed

The Tonbridge *Equisetites* Bed is exposed in the north and south lane-banks at a short distance east of the road-bridge crossing the railway south of the Tonbridge tunnel. (One mile south-east of Tonbridge, Kent.)

Through several feet of rootlet-perforated rock near the top of the Ashdown formation, scarce rhizomes with ascending stems and descending roots frequently still attached, may be found amid a welter of fragmentary subterranean and aerial material of a similar kind. Most of the plants are equisetalean, and many probably belong to the species *E. lyelli* (Mantell). The matrix consists of thin alternations of fine sandstone, lenticular siltstone and silty shale. Signs of contemporaneous erosion are common. The broken ends of some ascending stems, for instance, may be observed to underlie sediments containing more rhizomes bearing roots and stems apparently disposed as in life. The tissues are represented by a ferruginous substance and are poorly preserved. The possibility that nearly all the plants represent drifted material has not been entirely ruled out.

Mantell's description [1] renders it likely that the bed continues north-westwards for at least ⅛ mile to the railway cutting south of the tunnel. Elsewhere in the Weald no sign of it has been found.

(b) The Brede *E. lyelli* Soil-Bed

The main features of the Brede *E. lyelli* Soil-Bed and the attendant Fragment Bed have been described under the designation of the 'Lower Wadhurst *E. lyelli* Soil-Bed' [6]. It is now proposed to drop this unsatisfactory name in favour of the above.

The bed has been proved to occur at the localities shown on the map (Fig. 55) and detailed in Appendix 1 (pp. 312–4). Throughout this area (so far as is known), the soil-bed represents a pure community of *E. lyelli* plants "growing" *in situ*. The casts are nearly always found in a transitional group of strata about 9in. thick, comprising alternations of shale and finely current-bedded (lenticular) siltstone.

Along the south-eastern margin of the area they become smaller and less numerous, and signs of contemporaneous erosion (such as churning up of the soil followed by regrowth of the vegetation) are not uncommon. Beyond the south-eastern margin (broken line, Fig. 55), the stem and rhizome-bearing layer has not been recognised,

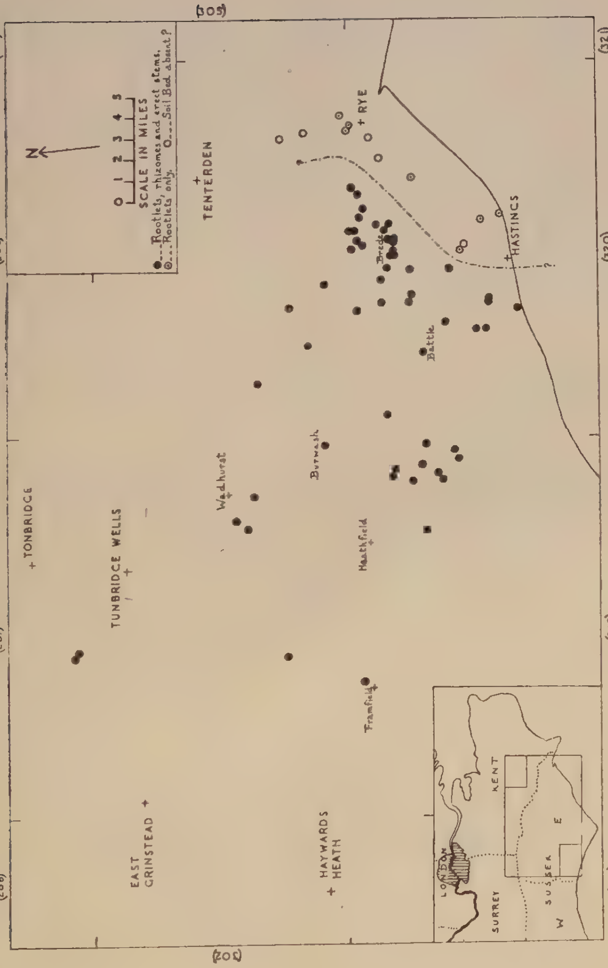

FIG. 55.—THE BREDE *E. LYELLI* SOIL-BED.

Sites of all known exposures. Marginal numbers and strokes denote Geological Survey 1-inch maps. Localities marked "Soil-Bed absent?" have failed to yield any plant organs *in situ* after intensive search.

and only occasional rootlets bear local testimony to its former presence (see Appendix 2). It is hoped to show, in another paper, that the N.E.-S.W. direction of current-movement thus indicated may also be recognised in the top Ashdown strata below.

Duration. Continued failure to locate any but small-scale erosional features in the area occupied by the complete soil-bed re-emphasises the essential tranquility of the scene. But how long it lasted is still uncertain. Possibly those facies in which the Fragment Bed consists of up to four thin partings (separated by one to two inches of barren rock) represent seasonal accumulations. Such evidence was obtained from Burwash (four partings at King's Hill—see Appendix 1), Sedlescombe (four partings near Hurst House), St. Leonards-on-Sea (three partings at Filsham Road) and Crowhurst (at least two partings near Crouchers Farm). Independent confirmation of this—for example, clear demonstration that different stems terminate at different partings in non-eroded localities—has been hunted for without success. But considering the general scarcity of peaty material, the general thinness of the rhizome-bearing layer and the relatively few 'arrested growth' phases of the rhizomes ([6], Fig. 56A), three or four years does not seem to be an under-estimate for many localities.

Compression. Almost certainly, the rhizomes and ascending stems were once roughly cylindrical in form, and doubtless their commissures, longitudinal vascular strands and nodal diaphragms were approximately equidistant for short distances. Biometric study of these organs and tissues in the fossilised state has, therefore, assisted in detecting, measuring and dating the subsequent compressional forces which acted upon them. The investigation was carried out by ascertaining the characteristic dimensions of a large number of rhizomes and stems whose matricial grades were known and whose orientations relative to dip and strike had been determined with some precision.

All the cross-sections of rhizomes discovered lying parallel to the bedding were found to be roughly elliptical in shape, their shortest axes being vertical to the bedding and their eccentricities decreasing with increase of coarseness of the enveloping matrix. This was so, no matter what the nature of local tectonics—for example, in localities where the dip varied from 0° to 103°. The compressional force had, therefore, been applied at right angles to the bedding and had acted most successfully in the argillaceous facies. There is, consequently, little doubt that its origin lay in the weight of overlying sediment.

Careful examination of the various matrices revealed no structural modifications attributable to increases in the lateral dimensions of the plants. Indeed, vertical compression had apparently occurred with relatively little horizontal spreading. This was investigated further by selecting casts having well preserved leaf-sheathes,

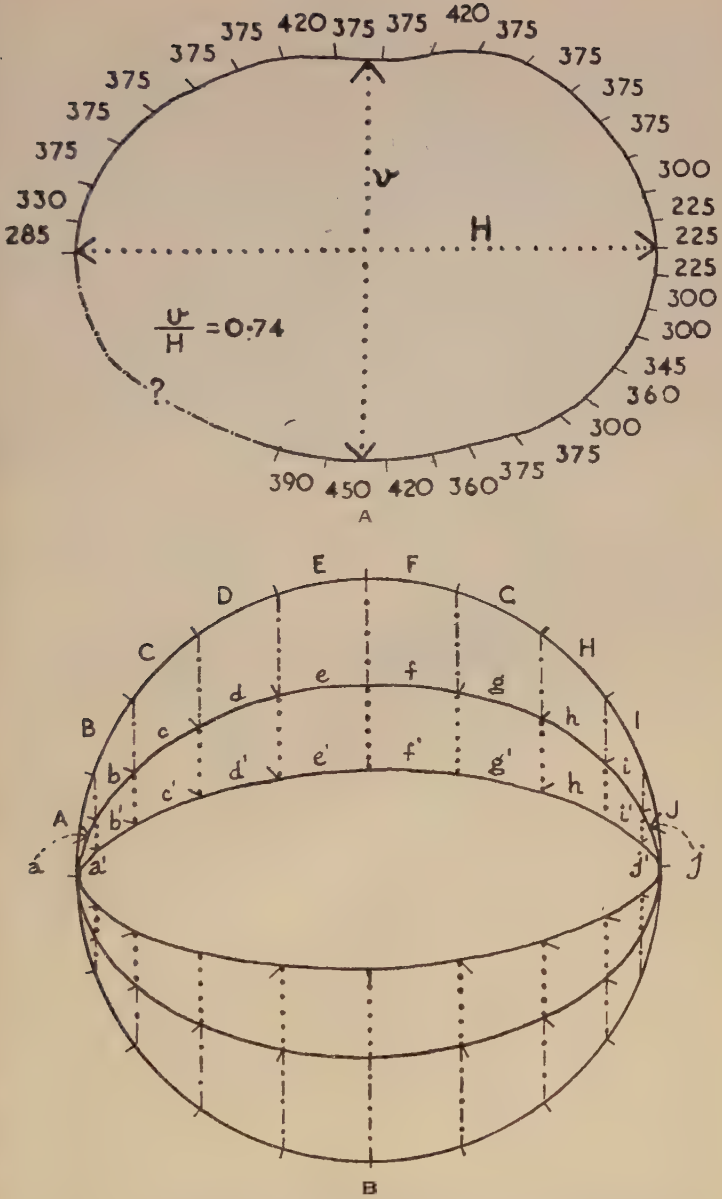

FIG. 56.—COMPRESSION OF *EQUISETITES LYELLI* (Mantell).

A. Vertical section of a horizontal rhizome from silty shale at Ludley Hill, Peasmarsh, Sussex. Commissural widths to nearest 15 μ.

B. Imaginary vertical sections of an originally horizontal and cylindrical rhizome (20 commissures) before and during two stages of vertical compression.

and measuring the chordal distances between the centres of the commissures at the nodes. In all cases, these were found to become wider on the upper and lower surfaces and progressively narrower laterally. A typical example is depicted in Fig. 56A (measurements in μ). The arrangement is readily explained in terms of the vertical compression of a cylindrical rhizome orientated horizontally and enclosed in a laterally immobile matrix. If, for example in Fig. 56B, the outer circle represents a cross-section of a horizontal rhizome having vertical diameter V and horizontal diameter H, and if A, B, C, ... represent its equally spaced commissures, then the two confocal ellipses may be held to represent ideal cross-sections at two stages during compression by a force acting parallel to V and resisted horizontally. Lateral spread being impossible, only the vertical axis will become appreciably abbreviated (to v and v′), and the hitherto equal commissural distances will become reduced to a, b, c, ... and a′, b′, c′, ... respectively, such that $A > a > a'$, $a < b < c$ . . . ., and $a' < b' < c'$ . . . . This is, of course, similar to the arrangement observed in nature.

For rhizomes with a fairly large number of leaf-teeth (*e.g.*, twenty or more) the centrally placed commissures such as E and F should undergo relatively little reduction. Thus E should normally be little greater than e, e′, etc. The *observed* relative reductions in the extreme lateral position ($\frac{a}{e}$, $\frac{a'}{e'}$, ... etc.) should therefore, approximate to the *actual* relative reductions ($\frac{a}{A}$, $\frac{a'}{A}$, ... etc.). Further, when the number of leaf-teeth is large the actual relative reductions in this position must closely approach the appropriate ratios of the major and minor elliptical axes ($\frac{v}{H}$, $\frac{v'}{H}$, etc.). The latter and the observed reductions will, therefore, be expected to approximate in practice (or $\frac{v}{H} \mathrel{\hat{=}} \frac{a}{e}$, $\frac{v'}{H} \mathrel{\hat{=}} \frac{a'}{e'}$, etc.). This is generally so ; but detailed comparison of all the data shows that $\frac{v}{H}$ is consistently rather greater than $\frac{a}{e}$, as exemplified in the following table :

Locality	Number of leaf-teeth on rhizome	Matrix	$\frac{v}{H}$	$\frac{a}{e}$
Ludley Hill, Beckley, Sussex	48	Silt	0.85	0.55
,,	36	Silty shale	0.74	0.68 0.50 0.54 0.63
West Hill, Brede, Sussex	36	Shale	0.64	0.52

Similar results have been obtained using the longitudinal vascular strands. Specimens from the Balcombe *E. lyelli* Soil-Bed (p. 311) reveal the existence of statistically similar average degrees of compression in equivalent ranges of matricial grade. A few casts of *E. columnaris* Brongniart (from the Lower Oolite of Yorkshire) and some pith-casts of *Calamites* (from the Lower Coal Measures of Yorkshire) have also been observed to possess similar features.

The degree of compression in the Brede Soil-Bed was nearly constant along any one rhizome provided it remained in the same kind of matrix. If this happened to be sandstone or grit, $\frac{V}{H}$ approached unity.

Some rhizomes contained distorted longitudinal vascular systems which had apparently resulted from twisting. Typical normal and twisted examples are illustrated in Figs. 57A and 57B.

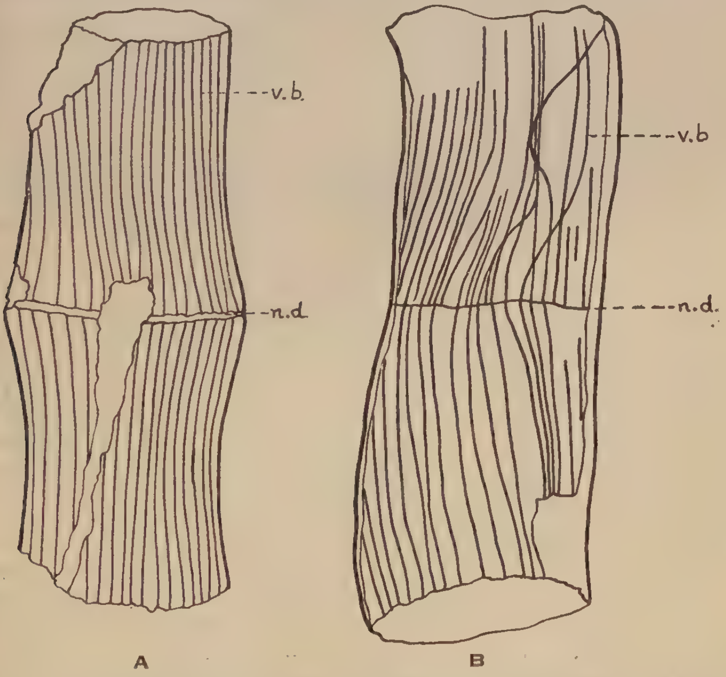

FIG. 57.—RHIZOMATOUS PITH CASTS OF *EQUISETITES LYELLI* (Mantell).

A. Usual type showing longitudinal vascular bundles preserved as ferruginous ridges (v.b.) and still parallel; n.d. = nodal diaphragm; x 4 (from Baldslow Wood, Westfield, Sussex).

B. Distorted type showing twisted vascular bundles; x 4 (from West Hill, Brede, Sussex).

No changes of internodal length due to compression were detected in the horizontally disposed material. Neither was there any detectable correlation between the compressional data and the directions of dip and strike.

The ascending stems exhibited exactly similar features in those parts where they were originally horizontal or nearly so. Correspondingly, their vertical portions often bore signs of reduction in internodal length. Obliquely orientated casts possessed intermediate characters. Buckling was not uncommonly observed, especially at silt-shale junctions. Again no correlation between the compressional and tectonic data was established.

Though consistent with Walton's theory [3], the above observations do not prove that absolutely no lateral splay was caused by the compression. But clearly, if any such extension did occur, it did not fully compensate for the vertical reduction involved.

(c) The Broad Oak ? *Equisetites* Soil-Beds

During 1938 [4], several soil-beds enclosing fossil plants were detected in the lowest 9½ feet of alternating shales and lenticular siltstones which overlie the sandy strata of the Telham Bone-Bed at Reysons Farm, Broad Oak (Brede, Sussex). The plants observed were undoubtedly " growing " in place and were equisetalean in character, though much smaller than *E. lyelli*. Unfortunately, their preservation (as ferruginous casts) was so poor and the small exposure so badly weathered, that precise generic identification was impossible.

Both rootlets and vertical stems were represented. Horizonal breaks were difficult to detect owing to penetration of several of the earlier soils by the rootlets of those developed later. The total number of soils is, therefore, doubtful.

When the site was re-excavated in 1942, it was found that the final quarrying operations had removed most of the remainder of the soil-beds. Their areal extent must, indeed, have been less than 100 sq. ft. Doubtless they represented several fleeting colonisations of a small and actively growing mudflat or shoal.

(d) The East Grinstead Soil-Bed

The only known locality of this soil-bed is a quarry on the north side of the East Grinstead—Kingscote road (B2110) at Coombe Hill, three-quarters of a mile south-west of East Grinstead parish church. In the pale buff Lower Tunbridge Wells sandstone exposed at that place, there is a prominent carbonaceous band (0″ to 3″ thick) situated at about 50 feet above the base of the formation. Immediately beneath this carbonaceous band, the sandstone is penetrated by numerous fossil roots preserved as ferruginous casts. They branch freely downwards and pass into finer rootlets often no more than 0.5 mm. across. Above the carbonaceous band, the sandstone is occasionally penetrated to a height of eight or nine inches by thin erect stems similarly preserved. So far, no continuity between the two systems has been proved and (owing to their inferior preservation) the exact identity of each is still unknown. At the most, it can only be said that they are probably not equisetalean.

Within the carbonaceous layer, cylindrical siltstone casts of plant rhizomes are occasionally found. They vary up to ½ inch in diameter, and bear both ascending stems (2-3 inches long and about ¼ inch in diameter) and descending rootlets. Their preservation is too poor for more precise determination.

(e) The Balcombe *E. lyelli* Soil-Bed

The road-cutting (B2036) running southwards from Balcombe (Sussex) railway station has for several years exposed a well developed *E. lyelli* soil-bed near the top of the Grinstead Clay. During the war, nearly quarter of a mile of this roadside was strewn with vast quantities of rhizomes and stem- and rootlet-perforated lenticles of pale grey siltstone.

The lithological details and mode of preservation are exactly similar to those in many parts of the Brede *E. lyelli* Soil-Bed. Often the plants are so crowded that their rhizomes and ascending stems twine around each other. Only one soil has been recognised.

No trace of other plant species has been found, and a pure community, therefore, appears to be represented.

IV. THE ROOTLET-BEDS

For the time being at any rate, the lack of structural detail in these soil-remnants presents an insuperable barrier to their correlation and interpretation. The rootlets seldom consist of more than downward branching pipes filled with sediment of distinctive colour or texture.

Palaeontological zoning by means of ostracods [5] seems to offer the only hope of elucidating their succession. In this connection, it may be noted that the rootlet-bed near Ore (Appendix 3) has yielded *Ulwellia menevensis* Anderson. Mr. P. C. Sylvester-Bradley, B.Sc., F.G.S., kindly identified the specimens.

V. SUMMARY

The following appear to be the more significant of the new facts :

(1) Both soil- and rootlet-beds are frequent in the strata examined. It follows that the basin of deposition must have been shallow during much of Lower Wealden time.

(2) All but one (d) of the soil-beds occur in *transitional* strata of very similar aspect. The upward change involved may be from dominantly arenaceous to dominantly argillaceous

facies, or *vice versa*—which, appears to be irrelevant. Evidently, the conditions necessary for colonisation (by horsetails, at least) were strictly limited. The nature of the strata lead to the conclusion that colonisation was controlled by one or more of the following factors: depth of water, amount of movement of the water, size-distribution of the sedimentary particles, chemical nature of the sediment, rate of accumulation of the sediment. That other factors were sometimes limiting is shown by the occasional presence of similar transitional strata without horsetails.

(3) Though the data are scanty, there are indications of a positive correlation between the lithological similarity of the soil-beds and the taxonomic similarity of the plants they contain.

(4) The bulk of the recognisable plant-tissues are preserved as ferruginous substances. Carbonised and 'coalified' remains are unusual at all the horizons. Doubtless a phase of oxidising conditions formed part of the history of each.

(5) Contemporaneous erosion was not normally severe. Where considerable, it was confined to the frontal (S.E.) margin of the delta-complex.

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APPENDIX 1

List of localities exposing the Brede *E. lyelli* Soil-Bed in its entirety.

	Locality and Type of Exposure.	Geol. Surv. 1-inch Map.
1.	Old claypit between main road and farm lane, ¼ m. S. of Salman's Farm, Penshurst, Kent	O.S. VI
2.	Ditch, W. side of farm lane, 300 yds. E. of No. 1	,,
3.	Lanebank opposite entrance to E. drive of Wadhurst Hall, ¾ m. S. of church, Wadhurst, Sussex	,,
4.	S. roadbank, Riseden Hill, 1½ m. S.W. of church, Wadhurst, Sussex	,,
5.	Quarry, E. side of lane, 2¼ m. S.W. of church, Wadhurst, Sussex	O.S. V

6.	Temporary scraping, ½ m. S. of Ford Brook, 1¾ m. N.W. of Hadlow Down, Sussex	O.S. V
7.	Sandpit, W. of road, King's Hill, ¾ m. S. of church, Burwash, Sussex	,,
8.	E. roadbank, N. end of Buckhurst Wood, 1 m. S.W. of church, Hawkhurst, Kent	,,
9.	Old sandpit, E. of lane, ½ m. N.E. of church, Salehurst, Sussex	,,
10.	S. lanebank, Northlands Lane, Bodiam, Sussex. (By church)	,,
11.	E. lanebank, ¾ m. S.S.E. of church, Ewhurst, Sussex	,,
12.	Old sandpit, W. side of Church Stile Lane, ⅓ m. N.E. of church, Framfield, Sussex	N.S. 319
13.	W. roadbank, ¼ m. S. of Cralle Farm, Warbleton, Sussex	,,
14.	Sand-quarry, E. of Hoads Wood, ¾ m. S.W. of church, Dallington, Sussex	,,
15.	S. lanebank, Sandhill Cottages, 1½ m. N.N.W. of church, Bodle Street, Sussex	,,
16.	Old sandpit, E. of lane, ¼ m. S.E. of No. 14	,,
17.	Old quarry in N.E. angle of crossroads, Redpale Farm (near Bucksteep Manor), 1¼ m. N.E. of Bodle Street, Sussex	,,
18.	E. lanebank, N. of Nunningham Stream, ⅓ m. N.W. of church, Bodle Street, Sussex	,,
19.	W. lanebank, S. of Christian's River, ½ m. N. of church, Bodle Street, Sussex	,,
20.	N. lanebank, 100 yds. W. of crossroads, Ponts Green, Sussex	,,
21.	Old sandpit E. of lane, 1 m. N.E. of Windmill Hill, Sussex	,,
22.	E. lanebank, ½ m. S. of Bray's Hill, Sussex (½ m. N.E. of No. 21)	,,
23.	Old quarry, W. of lane, 300 yds. S. of crossroads, Darwell Hole, Sussex	N.S. 320
24.	W. side of road-cutting, ½ m. N.W. of church, Battle, Sussex	,,
25.	Quarry, Beauport Park Estate, Telham, Battle, Sussex (1½ m. S.E. of Battle church)	,,
26.	N. bank of lane leading to Simpson's Farm, Green Street, Crowhurst, Sussex (½ m. S.E. of Crowhurst church)	,,
27.	Quarry, E. side of road-bridge close to Crouchers Farm, ½ m. S.S.W. of Green Street, Crowhurst, Sussex (¾ m. S.E. of Crowhurst church)	,,
28.	Quarry to N. of road, ½ m. N.W. of The Grove, St. Leonards-on-Sea, Sussex	,,
29.	Quarry, S. of road, opposite No. 28	,,
30.	S. roadbank, 150 yds. E. of No. 28	,,
31.	Sand-quarry (Hall & Co.), E. side of Filsham Road, St. Leonards-on-Sea, Sussex	,,
32.	Road-cutting, E. extremity of Baldslow Wood, Westfield, Sussex	,,
33.	S. lanebank, near Rocks Farm, Westfield, Sussex	,,
34.	N. lanebank, Sedlescombe Lane, 1 m. S.E. of church, Sedlescombe, Sussex	,,
35.	Old sandpit opposite Hurst House, Sedlescombe, Sussex	,,
36.	W. side of cutting, S.E. of roadbridge, Cripps Corner, Sedlescombe, Sussex	,,
37.	N. bank, Powdermills Lane, Brede, Sussex	,,
38.	New plough, 150 yds. N.W. of Sanatorium, Brede, Sussex	,,
39.	Old sandpit beside Waterworks Lane, 150 yds. W.S.W. of church, Brede, Sussex	,,
40.	Old sandpit, 100 yds. W.N.W. of No. 39	,,
41.	Temporary " Home Guard " trench, E. side of the Forstal, 100 yds. S.E. of church, Brede, Sussex	,,

42.	Sandpit, W. side of Hare Farm Lane, Brede, Sussex	N.S. 320
43.	Old sandpit, E. side of Hare Farm Lane, Brede, Sussex	,,
44.	W. bank of Stubb Lane, opposite Mount Pleasant Cottages, Brede, Sussex	,,
45.	W. bank, Stonelink Lane, Brede, Sussex	,,
46.	Old sandpit, N.E. corner of Big Heel Field, W. side of Stubb Lane, 1 m. N.E. of church, Brede, Sussex	,,
47.	Old sand-quarry, W. side of Maidlands Farm Lane, Brede, Sussex	,,
48.	Temporary road-cutting, near top of West Hill, Broad Oak, Brede, Sussex	,,
49.	E. lanebank, Beckley Furnace Lane, Brede, Sussex	,,
50.	W. lanebank, near top of Glasseye Hill, Beckley, Sussex	,,
51.	W. roadbank, near top of Maplestone Hill, Northiam, Sussex	,,
52.	Temporary pit, E. side of lane, 100 yds. N. of Glasseye Farm, Beckley, Sussex	,,
53.	W. lanebank, near top of Ludley Hill, Beckley, Sussex	,,
54.	Sandpit, Hayes Wood, Hayes Farm, Beckley, Sussex	,,
55.	N. lanebank, Eggs Hole, Peasmarsh, Sussex	,,
56.	E. lanebank, near top of Grovers Hill, ¾ m. W.S.W. of church, Peasmarsh, Sussex	,,

APPENDIX 2

List of localities exposing rootlets probably belonging to the Brede *E. lyelli* Soil-Bed.

	Locality and Type of Exposure.	Geol. Surv. 1-inch Map
1.	Inland sea-cliff, Houghton Green, Playden, Rye, Sussex	O.S. V
2.	Old sandpit, "Springfield," 200 yds. N.W. of church, Playden, Sussex	,,
3.	N. lanebank, New England Lane, Playden (near Rye), Sussex (S.E. of Playden church)	N.S. 320
4.	Old sandpit, Simpson's Farm, 200 yds. N.N.W. of church, Icklesham, Sussex	,,
5.	W. lanebank, near top of Hazelhurst Hill, ½ m. N. of church, Great Ridge, Ore, Sussex	,,
6.	Quarry, S. side of road, Fairlight Place Farm, Fairlight, Sussex	,,
7.	Sea-cliff, W. side of Fairlight Glen, Fairlight, Sussex	,,

APPENDIX 3

List of localities exposing other Rootlet-Beds.

	Locality and Type of Exposure.	Geol. Surv. 1-inch Map
1.	Hook Quarry, West Hoathly, Sussex (Grinstead Clay—near base)	O.S. V
2.	Reservoir shaft opposite Castle Farm, Mountfield, Sussex (Wadhurst Clay—in red and green mottled shales and grey lenticular siltstones near top)	N.S. 320
3.	Waterfall Wood, Peasmarsh, Sussex (Wadhurst Clay—in dark ostracod-shales 12 ft. above sandy horizon of Telham Bone-Bed)	,,
4.	E. lanebank, 1,000 yds. N.N.W. of church, Ore, Sussex (Wadhurst Clay—in dark ostracod-shales beneath sandy horizon of Telham Bone-Bed)	,,
5.	Cliff-section, Fairlight, Sussex (Ashdown Beds—'Fairlight Clay' facies)	,,

NOTES ON THE GEOLOGY OF THE COUNTRY ROUND SEVENOAKS, KENT

Together with a Report of a Field Meeting at Dunton Green and Dryhill, near Sevenoaks, on Saturday, 12th May, 1945

By C. W. WRIGHT, M.A., F.G.S., and H. DIGHTON THOMAS, M.A., Ph.D., F.G.S.

1. The Gault at Dunton Green (by C. W. W.).

THE pit of the Dunton Green Brick, Tile and Pottery Works near Dunton Green Station is regularly visited by geologists and students, but, apart from a brief note and section given by Jukes-Browne (1900, p. 90) and the short reference by Spath and Stubblefield (1930), I can find no description of it. Since there is exposed a good section of Lower and Upper Gault with several interesting features a fuller description is given below.

The lowest horizon at present exposed is the top of the *dentatus* subzone of the Lower Gault, equivalent to part of Bed I at Folkestone. The present working floor of the pit lies just above an irregular band of black and dark grey phosphatic nodules which are mostly casts of ammonites and other fossils. Below these is dark grey clay with pyritic and other *Hoplites* of the *dentatus* group, mostly crushed. The nodule bed includes many ammonites characteristic of the *dentatus* subzone, such as *Hoplites dentatus* (Sow.), *H. spathi* Breistroffer, *H. paronai* Spath, *H. persulcatus* Spath and *H. similis* Spath. In addition, however, there are many that would normally be expected from the *intermedius* subzone above. These include *Hoplites* between *H. dentatus* var. *densicostatus* and *Dimorphoplites pinax* and between *H. dentatiformis* Spath and *D. doris* Spath, *Hoplites canavarii* Parona and Bonarelli and forms transitional to *Euhoplites pricei* Spath, *Eu.* aff. *aspasia* Spath, *Eu. loricatus* Spath, *Eu. subtuberculatus* Spath, and *Anahoplites* aff. *evolutus* Spath (including sulcate forms). Immediately above the nodules are to be found fragments of *Hoplites dentatiformis* Spath, *H. dentatus* var. *densicostatus* Spath, *H. escragnollensis* Spath and *Anahoplites praecox* Spath. The nodules therefore may be regarded as representing the upper part of the *dentatus* and the lowest part of the *intermedius* subzones.

Anahoplites intermedius Spath itself appears about three feet above the Bed I nodules just described and is abundant, though usually crushed, throughout the next seven feet of clay. Ten feet above the Bed I nodules and 12 feet below the main Nodule Bed (see below) there is a band containing uncrushed body chambers of *Anahoplites intermedius* Spath, *A. mantelli* Spath, *A. praecox* Spath and ? *Dimorphoplites* sp.

Ammonites are unfortunately scarce in the succeeding 10 feet of clay, although at four feet below the main Nodule Bed there is a scattered band of poorly preserved *Anahoplites planus* (Mantell), *Dimorphoplites* sp. and *Hamites* sp. This band is presumably the source of the *Dimorphoplites niobe* Spath recorded by Spath (1926, vol. i, p. 156) and is in the *niobe* subzone. I cannot at present, however, trace any upper or lower limit for this subzone.

Only an inch or two below the main Nodule Bed several species of *Dimorphoplites* occur (*D. tethydis* Bayle sp., *biplicatus* Mantell sp. and aff. *chloris* Spath). Dr. Spath has suggested to me that these specimens should be regarded as belonging to the Nodule Bed, where all three species occur. They are, however, in a distinct preservation from that of the Nodule Bed fossils and definitely occur below the base of the nodules in several places in the pit. The lowest horizon from which Dr. Spath records the three species together is the subzone of *Dipoloceras subdelaruei* Spath, which is present in this section since the index fossil has been found. My only specimen of this species, however, found loose on the talus, is in more ferruginous material than the *Dimorphoplites* under discussion and it is in my view possible, though unlikely, that they attest the base of the *lautus-nitidus* subzone. Further collecting may elucidate the problem. It is at any rate clear that Lower Gault at least as high as the *subdelaruei* subzone is represented in the clay below the Nodule Bed.

The Dunton Green Nodule Bed is justly well-known for the abundance of its ammonites. It contains about 30 species from the top three subzones of the Lower Gault (*lautus-nitidus*, *daviesi* and *cristatum*) and represents in condensed form clays which at Folkestone are about nine feet thick, though even there there are several nodule beds which are evidence of condensation.

The common ammonites in the Nodule Bed are *Euhoplites* (especially *truncatus* Spath and *armatus* Spath), *Dimorphoplites* (*biplicatus* Mantell sp., *tethydis* Bayle sp., *chloris* Spath and *glaber* Spath), *Epihoplites* (*trifidus* Spath sp. and *compressus* Parona & Bonarelli sp.), *Anahoplites* (*planus* Mantell sp., *splendens* Mantell sp. and *daviesi* Spath) and *Hamites* (*gibbosus* Sowerby and *maximus* Sowerby). *Dipoloceras cristatum* (Brongniart) occurs, but is rare. There are also occasional specimens of *Hysteroceras capricornu* Spath, *H. semicornutum* Spath, *H.* aff. *simplicosta* Spath and *Beudanticeras subparandieri* Spath, but the hoplitids far outnumber the other groups.

Other fossils include lamellibranchs (especially *Nucula ovata* Sowerby, *N. pectinata* Sowerby, *Inoceramus concentricus* Parkinson, *I. subsulcatus* Woods and *I. sulcatus* Parkinson), gastropods (mostly Aporrhaidae) and the typical crabs *Palaeocorystes stokesi* (Mantell) and *Eucorystes broderipi* (Mantell).

The subzone of *Hysteroceras orbignyi* Spath, with which the Upper Gault begins, consists of dark grey clay below, rapidly changing to the characteristic light grey and, later, fawn and mottled marly clay above. In the lower part ammonites are abundant, hoplitids predominating. *Dipoloceras cristatum* (Brongn.) still occurs rarely and *Hamites maximus* Sowerby and *H. incurvatus* Brown are moderately common. However, the most abundant are *Anahoplites planus* (Mantell), *Epihoplites compressus* (Parona & Bonarelli), *E. trifidus* (Spath), *Euhoplites armatus* Spath, *Eu. trapezoidalis* Spath, *Eu. ochetonotus* (Seeley), *Eu. subcrenatus* Spath and, higher up, *Eu. inornatus* Spath. *Hysteroceras* is rare until a band about seven feet above the Nodule Bed, containing abundant *H. orbignyi* Spath.

Inoceramus sulcatus Parkinson is extremely common throughout the *orbignyi* subzone and especially in a stony band which also contains *Isocrinus* ossicles, crushed echinoids and occasional crushed *Deiradoceras*, about seven and a half feet above the Nodule Bed. *Nucula pectinata* Sowerby, *N. ovata* Sowerby, *N. bivirgata* Sowerby and *Dentalium* are among the many small molluscs common at this horizon. The cirripedes *Arcoscalpellum arcuatum* (Darwin) and *Cretiscalpellum unguis* (Sowerby) are not uncommon.

A band 13 feet 3 inches above the Nodule Bed contains *Hysteroceras varicosum* (Sowerby) and *Euhoplites alphalautus* Spath as well as *H. orbignyi* Spath, and may therefore be regarded as marking the base of the *varicosum* subzone. It is probably the source also of specimens of *Anisoceras subarcuatum* Spath and *Idiohamites favrinus* Spath picked up loose in the pit.

Thus we find at Dunton Green about 42 feet of clay compared with perhaps 40 feet at Folkestone for the same subzones. Beds V to VIII at Folkestone, about nine and a half feet thick, are represented at Dunton Green by the three or four inch thick Nodule Bed. On the other hand the *intermedius* subzone is about 12 feet thick at Dunton Green against half that thickness at Folkestone.

The table that follows summarises the zoning discussed above and shows the particular horizons at which ammonites occur in the pit. These are recorded as being so many feet and inches above or below the Nodule Band, which is the most readily identifiable datum line in the section.

Zones	Subzones	Lithology	Distance above or below Nodules	Some of the fossils found *in situ*
inflata		Soil & weathered pale grey clay, 6 feet		
	varicosum	Mottled fawn & light blue-grey clay shading to light grey below, 12 feet	+13′ 3″–13′ 9″	*Hyst. varicosum, orbignyi, Pervinquieria* sp., *Eu. alphalautus*
			+10′	*Eu. subcrenatus* (fide Spath)
			+7′ 6″	*Hyst. orbignyi, Ham. maximus* var. *rectus*
	orbignyi		+7′	Hard Band with *Deiradoceras, Ino. sulcatus, Isocrinus, Cyclocyathus*
		Medium grey clay, 6 feet	+2′ 6″–3′ 6″	*Eu. armatus, inornatus, Epi. trifidus*
			+9″–1′ 6″	*Ana. planus, Epi. compressus, Eu. subcrenatus, ochetonotus, armatus, Ham. incurvatus*
lautus	*cristatum* *daviesi* *lautus*	Nodule Bed, 3-4″		Many fossils (see text)
	? *lautus* *subdelaruei*	Lightish grey clay, slightly mottled, darkening below	—2″	*Dimorph. biplicatus, tethydis, chloris*
			—5″	*Ana. planus, Eu.* sp.
dentatus	*niobe*		—4′	*Ana. planus, Dim.* sp., *niobe* (fide Spath)
	intermedius	Dark grey clay 23 feet in all	—12′	*Ana. intermedius, mantelli, praecox, Dimorph.* sp., *Ham.* sp.
			—13′ 6″	*Ana. praecox*
			—17′	Crushed *Ana. intermedius* & *Ino. concentricus*
			—19′	Crushed *Ana. intermedius*
			—22′ 3″	*A. praecox, Hop. dentatiformis, escragnollensis, dentatus* var. *densicostata*
		Bed I Nodules	—22′ 6″	Many fossils (see text)
	dentatus	Dark grey clay seen to 1′		Crushed and pyritic *Hoplites*

II. The Hythe Beds at Dryhill, near Sevenoaks (by H. D. T.) Plates 24, 25.

The structures exposed at Dryhill, about 1½ miles west of Sevenoaks Station,[1] have never been described since Fitton first recorded them in 1836 (p. 134). There a wooded ridge rises fairly sharply from the depression formed by the soft Sandgate Beds south of the Folkestone Sands running through Bessel's Green. It is cut into by two quarries in line opened by the Sevenoaks Urban District Council, the larger westerly one having been recently disused. These show that the Hythe Beds are brought up by two nearly E.-W. anticlines,[1] the axes of which are pitching and converging slowly eastwards. The folding is sharp, and dips up to 90° can be measured on the limbs of both anticlines—the highest dips are to be seen in the newer quarry (Pl. 24). In the old quarry (Pl. 25) over 60 feet of Hythe Beds are exposed. The facies developed is that of the Kentish Rag, the beds consisting of alternating harder limestones (" rag ") and softer sands (" hassock "). The limestones (which are quarried for road-metal) are grey, weathering brown, and are somewhat sandy, grains of glauconite being frequently visible in hand specimens. They are mostly about one foot thick, though a few are two feet. The beds of " hassock " (so much waste in the quarrying operations) are greenish-yellow, glauconitic sands, the thickest of which is 2ft. 6in. thick. Pink or purplish chert nodules are developed irregularly in some of the limestones (*e.g.*, in the upper part of the northern face of the western quarry), while small, dark brown, phosphatic nodules, weathering pale buff, occur sporadically in the sands. The limestones are broken by joints and irregular cracks clearly caused by the buckling movement, and in places small faults occur—one of these is seen in the southern part of the eastern face of the disused quarry. Calcite veining up to two inches in thickness occurs in places along some of the joints.

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[1] The map reference for the present working pit is National Grid Reference 502553.

Both the limestones and the sands are fossiliferous, but the latter yield the richer fauna, mainly as internal casts, though the brachiopods, *Exogyra sinuata* (J. Sowerby), and the belemnites retain their calcite skeletons. The fossils of the sands include :—

Serpula sp.
Cyclothyris sp. cf. *gibbsiana* (J. de C. Sowerby)—common.
Ornithella sp. cf. *tamarindus* (J. de C. Sowerby).
Cucullaea sp.
Exogyra sinuata (J. Sowerby)—abundant, in all stages of growth from young to large adult individuals (also in the limestones).
Pseudolimea parallela (J. Sowerby).
Thetironia minor (J. de C. Sowerby)—common.
Trapezium sp.
Trigonia ornata d'Orbigny—abundant.
T. carinata Agassiz—rare.
Nautilus radiatus J. Sowerby—common (also in the limestones).
Deshayesites sp.
Tropaeum sp. (also in the limestones).
Neohibolites sp.—abundant.

I am indebted to Dr. L. R. Cox, Dr. H. M. Muir-Wood and Dr. L. F. Spath, F.R.S., for confirming identifications of the fossils.

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[1] The folds are part of a series occurring near Sevenoaks which recall some of the structures described by Hollingworth, Taylor & Kellaway (1944).

III. Report of Field Meeting at Dunton Green and Dryhill on Saturday, 12th May, 1945 (by the Directors, H. Dighton Thomas and C. W. Wright).

The first field meeting after VE-Day was held in brilliant, hot sunshine. From the footpath a little south of Dunton Green Station, the general geology of the area was indicated. The party then entered the clay-pit of the Dunton Green Brick, Tile and Pottery Works, Limited (by permission of Mr. H. R. Breething), and the subzones of the Gault exposed there were pointed out. Fossils were collected at various levels, abundant ammonites being found, particularly in the *dentatus* subzone at the base of the pit, in a band in the *intermedius* subzone 11 feet higher up, and in the well-known Dunton Green Nodule Bed.

The party then joined the main road, but, soon after crossing the River Darent, followed a road which runs to the south-west, and which climbs the dip-slope of the Folkestone Sands to the Westerham Road. Numerous exposures in the ginger-coloured sands were noted on the way, and a roadside section a little west of Bessel's Green was examined, which showed the typical current-bedding and development of " carstone." Thence a field-path led across a depression formed by the Sandgate Beds to the Sevenoaks U.D. Council's quarries at Dryhill, where Mr. J. Randerson, M.Inst.M. and Cy.E., the Council's Engineer and Surveyor, met the party and gave an account of the working of the quarries. The geological structures were examined, and typical fossils collected, especially from the highly dipping sands exposed in the cutting joining the two quarries. A picnic tea was held, and Dr. Emily Dix proposed a vote of thanks to Mr. Randerson, to the two Directors, and to Mr. R. J. Bell (Secretary of the meeting).

Thirty-five members attended the meeting.

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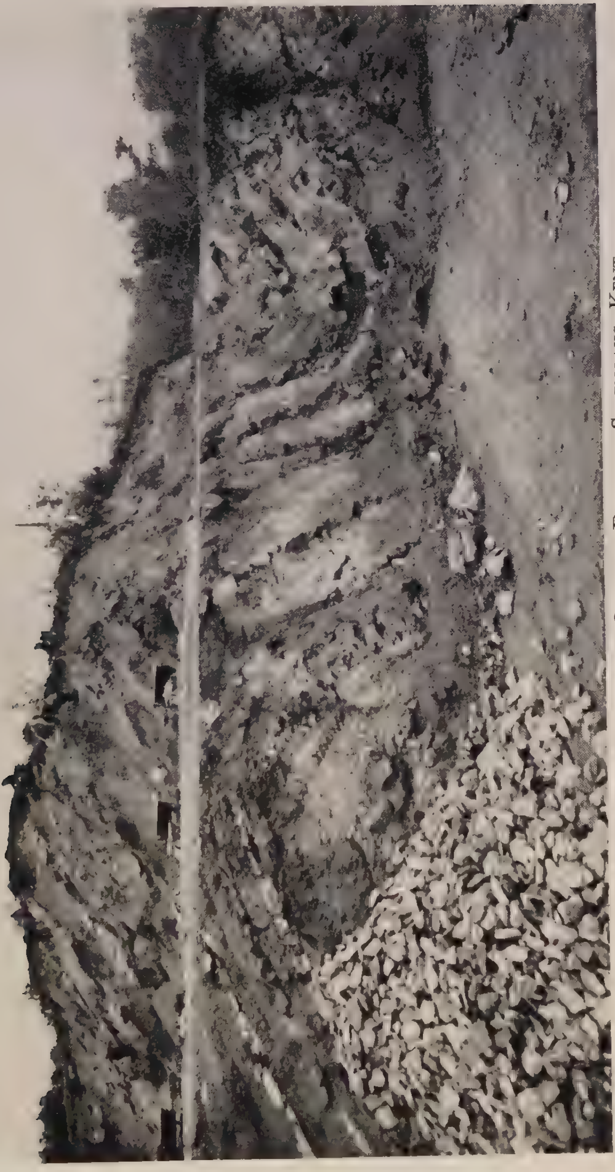
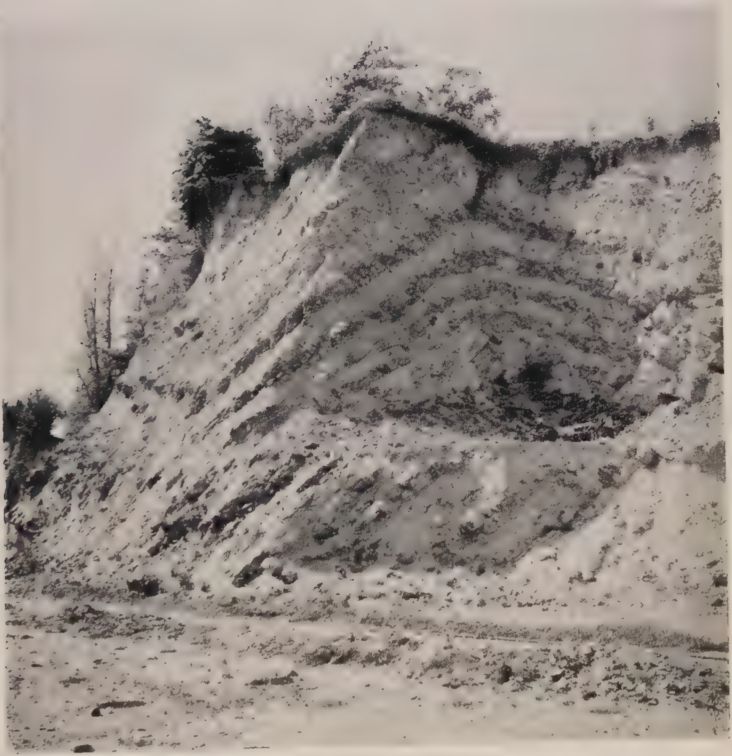


FOLDED HYTHE BEDS, NEW QUARRY, DRYHILL, SEVENOAKS, KENT.

[*To face p.* 320.



FOLDED HYTHE BEDS, OLD QUARRY, DRYHILL, SEVENOAKS, KENT.

V. Explanation of Plates 24 and 25

Plate 24.—View (May, 1945) of eastern face of the new (eastern) Dryhill Quarry, showing an anticline and syncline in Hythe Beds. Note the nearly vertical dip in the septum of the folds. The hard, prominent bands are the " rag." [Photo : E. F. Blackbourn, A.M.Inst.C.E., A.M.Inst.W.E.]

Plate 25.—View (1946), looking west, of the Hythe Beds in the old (western) Dryhill Quarry. To the left (south) of the anticline a sharp syncline is shown, cut by the steep face running slightly obliquely to the strike. [Photo : A. J. Bull, M.Sc., Ph.D., F.G.S.]

JAMES HUTTON'S "THEORY OF THE EARTH," 1795

(Hundred and fiftieth anniversary of the birth of modern geology)

By S. I. TOMKEIEFF, D.Sc., F.G.S.

"THE classical order dying from over-abstraction and false generality, had been devoured by its own children, the Enlightened philosophers." So writes J. Barzun (*Romanticism and the Modern Ego*, 1943) viewing the end of the classical age and the beginning of the romantic in perspective from the standpoint of the twentieth century. This 'over-abstraction and false generality' is apparent in what may be called a truly 'classical' view of geology, Thomas Burnet's *Theory of the Earth*, published in 1697. He says, "And so the Divine Providence, having prepar'd Nature for so great a change, at one stroke dissolv'd the frame of the old World, and made us a new one out of its ruines, which we now inhabit since the Deluge" (p. 53). Contrast Hutton's *Theory of the Earth* published just a century later in 1795, and still based on the view that the present earth is made out of the ruins of the old—"The natural operations of this globe, by which the size and shape of our land are changed, are so slow as to be altogether imperceptible to men. . ." (II, 563)[1] and "It is this operation of nature which we see performed, more or less, every day, which some natural philosophers have such difficulty in admitting at all, and which others overlook in seeking for some wonderful operation to produce the effect in a shorter time." (II, 467).

Hutton, while still feeling the influence of the Age of Reason, stood on the threshold of a new age which for geology meant a new birth as a science founded on observation and freed from the trammels of theology. The year 1795 saw the publication of two 'Theories.' In one :—*Théorie de la Terre*, J. C. Delamétherie looks back on the past state of geology, in the other *Theory of the Earth*, J. Hutton looks towards the future of this science. By a strange coincidence the same year is marked by three other important events in the history of geology, for it was in 1795 that Cuvier read a paper in which the remains of extinct mammals were correctly described for the first time, William Smith arrived at the idea that strata can be identified by organic fossils, and finally Goethe published the first outline of comparative anatomy—a prerequisite for any scientific work in vertebrate palaeontology.

This sudden rise of geology as a systematic science was predetermined by the work accomplished since the middle of the eighteenth century. The remarkable progress achieved during this short interval was due to many and various causes, among which one may be singled out for mention—the rapid development of mining and agriculture in connection with those industrial changes normally labelled ' the industrial revolution.' The development of systematic mineralogy—the prelude to systematic geology—was definitely conditioned by the intensive development of mining in such countries as Sweden and Saxony. It was in Freiberg in Saxony that Werner began in 1775 to teach geognosy in the Mining Academy, thus creating an impulse which pushed geology forward on its road of progress. The magnificent descriptive works of Guettard, Desmarest, Dolomieu, Arduino, Pallas, Saussure and Whitehurst, testify to the energy and acumen of the eighteenth century observers, but it was already obvious, even to them, that the facts were outrunning the theories. These theories, hoary with age, were survivors of a mythological, pre-scientific age and were absolutely incapable of explaining newly acquired facts. The theory of the aqueous origin of all rocks, nearly as old as Thales, the doctrine of the universal flood, even older, volcanoes as burning mountains, earthquakes piling up mountains and rending valleys, all these extraordinary and often supernatural phenomena undermined as they were by the new empirical currents, yet cluttered up the main stream of the science of geology and made the navigation difficult, if not impossible.

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[1] All the quotations from Hutton are from his *Theory of the Earth*, 1795, and the references in brackets are to volume and page.

The relation between theories and facts is reciprocal. Theories are built upon facts and facts are illuminated, and new facts are discovered, in the light of theories. Thus the introduction of new theories in geology at the end of the eighteenth century not only provided a powerful stimulus to the development of this science, but actually transformed the whole of it. This ' Great Renewal ' was mainly due to the efforts of three men—A. G. Werner (1743–1817), James Hutton (1726–1797) and William Smith (1769–1839). Werner inspired numerous field geologists and provided them with the idea of stratigraphical succession on a lithological basis. Smith modified the Wernerian scheme of stratigraphy by his inclusion of palaeontological data. Hutton provided geology with its inner dynamics and with a set of fundamental principles.

Needless to say the Industrial Revolution was not the sole stimulus to the development of geology in this period. The new modern scientific outlook developed during the seventeenth century and made manifest in Newtonism had produced a rapid growth in physics, chemistry and biology, which, towards the close of the eighteenth century, had become sufficiently mature to provide a solid foundation for the science of geology. The strength of Werner was based on the new mineralogy—an offshoot of the new chemistry—the Huttonian theory is a logical extension of Newtonism, and Smith's idea would be barren without the new biology. Nor can the development of the new geology be dissociated from the intellectual climate of the period. What is usually called the Romantic Movement was marked by a growing historical sense and a deeper understanding of nature. As Wordsworth said :

> The sounding cataract
> Haunted me like a passion ; the tall rock,
> The mountain and the deep and gloomy wood,
> Their colours and their forms were then to me
> An appetite.

While the poet could satisfy his 'appetite' in poetry, the same urge stimulated the hundreds of 'Knights of the Hammer' who took the field in the beginning of the last century.

The study of the stimulus provided by the industrial revolution alone would cover a large field of research. That geology is intimately connected with mining is obvious enough. The fifty years of the 'heroic age' of geology (1775-1825) correspond with the first phase of the industrial revolution. The limits of this period are marked by two important events—the first industrial application of Watt's steam engine (1775) and the first passenger railway worked by Stephenson's steam locomotive (1825). These two dates roughly correspond to the beginning of the rise of the curves for coal and pig-iron production in Great Britain. The agrarian revolution is also not without its influence on the development of geology as it is shown by the careers of Hutton and W. Smith.

The more general stimulus exercised by the circulation of new ideas and incentive of new demands can be narrowed down in one case to the interplay of three active minds. The chemist Joseph Black, James Hutton and James Watt were a trio of intimate friends. The theory of latent heat as propounded by Black inspired Watt with his idea of a separate condenser and thus paved the way for the invention of the new steam engine. The same theory and the results of Black's work on carbonic acid and on the modifying effect of pressure on the effect of heat greatly influenced Hutton in the construction of the theory of the earth. While Black seems to have provided much of the spiritual inspiration of the combination, Watt, who was Hutton's companion on some of his geological excursions, must have influenced him in no small degree. In fact we know that it was Watt who provided him with a geological map of Cornwall and so made an important contribution towards the Huttonian theory of the intrusive origin of granite (I, 214).

Hutton, like Priestley and others, was unfortunate in his choice of a time for springing new conceptions on the world. The heresy hunting and heretic baiting which were characteristic sports of the latter half of the eighteenth century were intensified by the reaction to the French Revolution in this country. His principal work was published in 1795 and was immediately subjected to a spate of ignorant and prejudiced criticism. The *Theory of the*

Earth was published in two volumes. Parts of the manuscript of a third volume were discovered a century later and published in 1899. Other works were his first paper on the subject of the theory of the earth, read before the Royal Society of Edinburgh in 1785 and published in its Transactions in 1788, and a paper on the subject of granite read before the same society in 1790–1791 and published in 1794. After Hutton's death in 1797 his friend John Playfair published in 1802 a very clear exposition of his doctrine in a book entitled *Illustrations of the Huttonian Theory*. The work of Hutton was, however, eclipsed by the temporary ascendency of Wernerism and only brought to light by the genius of Charles Lyell in 1830. The very title of Lyell's book, *Principles of Geology* : *being an inquiry how far the former changes of the earth's surface are referable to causes now in operation*, and his opening sentence : "Geology is the science which investigates the successive changes that have taken place in the organic and inorganic kingdoms of nature . . ." are vivid reminders of the influence of Hutton on Lyell's thought and are symbolic of the new geology—dynamic, actualistic, uniformitarian. This classic book of Lyell's in form and content served as a pattern for the numerous text-books on this subject written since 1830. This great succession of books forms a worthy and enduring monument to the genius of Hutton, who dominates the science of geology in a manner almost unique in the sciences.

There is no room in this article to discuss the sources of the Huttonian doctrines. Science is a complex social process in which the individual worker gathers many threads from the past and weaves them into an intricate pattern of his own. In the case of Hutton the pattern proved to possess an enduring quality.

Hutton was primarily a philsopher of nature, a virtuoso of the Age of Reason, born and bred in the atmosphere of Newtonian philosophy, deism and naturalism. His approach to science was coloured by the prevalent philosophy, which rejected supernaturalism in favour of naturalism, *a priori* reasoning in favour of *a posteriori* reasoning, movement in favour of rest. "I do not pretend," writes Hutton on the subject of De Luc's system of geology, "as he does in his theory, to describe the beginnings of things ; I take things such as I find them at present, and from these I reason with regard to what which must have been. When, from a thing which is well known, we explain another which is less so, we then investigate nature ; but when we imagine things without a pattern or example in nature, then, instead of natural history, we write only fable." (I, 173, footnote.) In certain respects, however, he is still immersed in the atmosphere of the previous age and the idea of final causes runs like a red thread through all his book. "When we trace the parts of which this terrestial system is composed, and when we view the general connection of those several parts, the whole presents a machine of a peculiar construction by which it is adapted to a certain end. We perceive a fabric, erected in wisdom, to obtain a purpose worthy of the power that is apparent in the production of it." (I, 3.) This purpose which Hutton sees in the Universe and which is a reality also to certain of the Romantics—such as Shelley—has since been completely overlaid by the mechanistic approach to science which characterises the nineteenth century. It is not, however, beyond the bounds of possibility that the more philosophical approach to science, which is gaining ground today, will re-instate wholly or in part the idea which permeates Hutton's *Theory of the Earth.*

The earth, according to Hutton, is an organic whole, and " We are thus led to see a circulation of the matter in this globe, and a system of beautiful economy in the works of nature. This earth, like a body of an animal, is wasted at the same time that it is repaired. It has a state of growth and augmentation ; it has another state, which is that of diminution and decay. This world is thus destroyed in one part, but it is renewed in another ; and the operations by which this world is thus constantly renewed, are as evident to the scientific eye, as are those in which it is necessarily destroyed." (II, 562.)

The earth, according to Hutton, is also a dynamic whole and its changes are cyclic—denudation is followed by accumulation of sediments in the ocean, and these, hardened by the internal heat of the earth, are again raised to the surface and so on in cycles in which " we find no vestiges of a beginning,—no prospect of an end." (I, 200.) Hutton, as if inspired by Watt's invention of the steam engine, saw the cyclic processes of the earth as set in motion by the internal heat of the earth and by the external heat of the sun, which in turn causes the circulation of water—" Fire and water are two great agents in the system of this earth." (I, 290.)

This idea of cyclic change dominates Hutton's theory of the earth, although the additional emphasis of a particular name had to wait many years. For the last thirty years or so the cyclic process has been accepted as ' the metamorphic cycle,' but this, though convenient, lacks accuracy in that ' metamorphic ' is made to cover all kinds of changes, including those due to weathering, diagenesis and anatexis. A commemorative article on Hutton may be a suitable time and place to suggest a new and I hope a more accurate title for the process which he was the first to define. I should like here to propose the term ' geostrophic cycle ' (from the Greek *strophe*—a turning, or *strepho*—to change) for the major cycle of changes in the earth.

According to Hutton existing and actually observable causes should be sought for to explain these changes, and the ' present as the key to the past ' is the dominant note of Huttonian philosophy. " It is from this actual state in which the solid parts of the earth are found, that I have endeavoured to trace back the different states in which they must have been ; and, by generalising facts, I have formed a theory of the earth." (I, 234.) In discussing denudation he writes—" The object which I have in view, is to show, first, that the natural operations of the earth, continued in a sufficient space of time, would be adequate to the effects which we observe ; and, secondly, that it is necessary, in the system of this world, that these wasting operations of the land should be extremely slow " (II, 467), and, " What reason have we to look out for any other causes, besides those which naturally arise from that constitution of things ? " (II, 468.)

Towards the end of the eighteenth century the heroic conception of human history was being replaced by one of gradual development composed of the actions and thoughts of a multitude of men and women. Condorcet was the exponent of this idea and his book was published in 1794. To the heroic conception of human history corresponded the catastrophic conception of earth's history. This Hutton replaced by what may be called gradualism. " But though," he writes, " in generalising the operations of nature, we have arrived at those great events, which, at first sight, may fill the mind with wonder and with doubt, we are not to suppose, that there is any violent exertion of power, such as is required in order to produce a great event in little time ; in nature, we find no deficiency in respect of time ; nor any limitation with regard to power. But time is not made to flow in vain ; nor does there ever appear the exertion of superfluous power, or the manifestation of design, not calculated in wisdom to effect some general end." (I, 182.) In a more concise form this idea is restated by Playfair as follows : " Time performs the office of *integrating* the infinitesimal parts of which this progression is made up ; it collects them into one sum, and produces from them an amount greater than any that can be assigned." (Illustrations, 128.) The mathematical mind of Playfair grasped the true meaning of the Huttonian conception—' the integration of infinitesimal events '—a philosophical extension of the Newtonian calculus.

Thus the geostrophic cycle is composed of a multitude of individually small and various events which between them are responsible for all the changes in rocks and minerals. The first phase is the elevation of the continental masses, the intrusion and extrusion of magma, folding and faulting. This is followed by the weathering, denudation and deposition in the sea of loose sedimentary material, which, under the influence of the pressure of succeeding sediments and of the internal heat of the earth, are gradually consolidated and finally fused and incorporated into the magma. These are not the actual terms used by Hutton, but all the parts of this process are discussed by him, sometimes in great detail, but in the majority of cases only as shadowy suggestions. Some of the processes are also wrongly interpreted. For instance, he attributes an igneous origin to flint and septarian nodules and insists that the consolidation of sediments was due to the effect of subterranean heat. On the other hand the processes of metamorphism and anatexis are only vaguely hinted at. In spite of these shortcomings, which provided an easy target to his opponents, his proofs of the igneous origin of granite and basalt, his discovery and correct interpretation of unconformity, his masterful study of the denudational effect of rivers and of their part in the sculpturing of the land, his suggestion that moving ice may be the agent of erosion and transport, and his ideas about weathering establish him not only as a master of theory, but also as an acute and accurate observer.

When the heat of the furious battle between the Neptunists and the Vulcanists was over, Hutton's ideas emerged triumphant and became the core of modern geology. This became evident soon after the publication of Lyell's *Principles of Geology* and already in 1839 we see W. H. Fitton writing about Hutton as follows: ". . . it was his fate to be too far in advance of his contemporaries. At a time when geological information was rare in every part of Europe, and in England almost unknown, he was, we firmly believe, a geologist of the highest order; and he combined such sagacity with great original views as to the scope and object of geological enquiry, in connection with other departments of physical science, and such a just anticipation of what it was likely to become in after years, that we know no other name, in the history of Geological Theory, which can be placed besides his own." (*Edinb. Rev.*, 1839, vol. 69, pp. 441-2.)

So much for Hutton as a geologist. His services to his own science are generally if not very deeply acknowledged, but he achieved something more. Geology plays its part in the general scientific scheme and Hutton's geological theories take their place in the development of the idea of evolution midway between Kant and Darwin.

FIELD MEETING AT LEIGHTON BUZZARD

Sunday, 11th August, 1946

Report by the Director : C. W. Wright, M.A., F.G.S.

TWENTY-ONE members met at Leighton Buzzard Station. In spite of depressing forecasts and threatening clouds the weather began and continued fine.

The first call was made at Messrs. Arnolds' pit at Billington Crossing. Here above the current-bedded Leighton Sands are exposed five feet of brownish gritty clay with phosphatic nodules, overlain by normal dark grey Lower Gault clay. The nodules in the brownish clay were the source of most of the specimens of the genera *Leymeriella*, *Sonneratia* and *Cleoniceras* described by Dr. Spath in his Monograph of the Ammonoidea of the Gault. Recent work has shown that each of the four bands into which the nodules are concentrated has to some extent its own fauna of ammonites and other fossils. This distribution could not be demonstrated in detail as the ammonites occur irregularly, but members found examples of *Leymeriella regularis*, the subzonal index, in the lowest nodule bed and, surprisingly, in the surrounding gritty clay. Mr. Grimsdale discovered a fine *Sonneratia*, between *S. kitchini* Spath and *S. obesa* Spath, in the second nodule bed which also produced a number of other fossils.

After briefly examining a patch of Boulder Clay in the north-east corner of the pit, which yielded some derived Jurassic fossils, the party walked by the light-railway line to the Shenley Hill road and thence to Messrs. Garsides' Munday's Hill pit. This adjoins the now filled in 21 Acre Pit, which lay immediately north of Nine Acre Pit (see the plan given in Lamplugh, 1922, p. 2).

The Leighton Sands in this pit, so long as they are not left to stain by weathering of the overlying carstone when the clay cover is removed, are dazzlingly white. Above them is a varying thickness of carstone (" iron pan "), often broken up and forming a conglomerate bed, and occasional lenses of brown or green sand and Shenley Limestone. Unfortunately no limestone lenticles were to be seen at the time of our visit, though three at least have appeared in the face in the last three years. However, their position in the succession was clearly demonstrated and a brief account was given of the controversy that arose out of the suggestion that they were of Cenomanian date (see Kitchin and Pringle, 1920 and Lamplugh, 1922).

In most of the section the carstone bed is succeeded by dark grey clay of the *dentatus* zone, but in the south-west corner of the pit there is intercalated some pale grey and brick red clay. The red clay was first noted by Toombs (1935, p. 434) and he seemed to imply that it was of comparable date to the dark grey clays above which were shown by him to contain ammonites of the *intermedius* subzone of the *dentatus* zone. However, the fauna of both the red and the pale grey clay which sometimes occurs above it is closely comparable with that of the limestone lenticles. It is, therefore, probable that the major stratigraphical break occurs above rather than below the red clay. Some of the characteristic brachiopods of the limestone were found in the clay on the occasion of our visit. Members were also able to collect numerous valves of the cirripedes *Cretiscalpellum unguis* (Sow.) and *Pycnolepas rigida* (Sow.) from the band noted by Toombs. It was obvious that the cirripedes and the associated *Isocrinus* had grown on the eroded upper surface of the carstone. The resemblance in many respects of the red clay to the red chalk, especially that of Speeton, is noteworthy.

A few ammonites from the *dentatus* and *lautus* zones and from the nodule bed at the base of the pale grey Upper Gault were collected.

The last section visited was Chamberlain Barn pit. The magnificent exposure of last year is now much overgrown, but there was a small stretch of the face freshly cleared. From this many *Beudanticeras* and a few *Douvilleiceras* were collected as well as some fragments of *Sonneratia.* Particularly interesting in this section, which closely resembles that in Arnolds' pit at Billington Crossing, is the occurrence in the thin conglomerate bed below the clay of pebbles of Shenley Limestone, which proves that the limestone was formed before the clays with nodules and, therefore, is at least as old as the *regularis* subzone of the *tardefurcata* zone.

The Association's thanks are due to Messrs. Arnolds and Messrs. Garsides who readily gave permission for the party to visit their pits.

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